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Aad, G.; ATLAS Collaboration

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## Observation of $WWW$ Production in $pp$ Collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector

G. Aad *et al.*\*  
(ATLAS Collaboration)

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This Letter reports the observation of  $WWW$  production and a measurement of its cross section using  $139 \text{ fb}^{-1}$  of proton-proton collision data recorded at a center-of-mass energy of 13 TeV by the ATLAS detector at the Large Hadron Collider. Events with two same-sign leptons (electrons or muons) and at least two jets, as well as events with three charged leptons, are selected. A multivariate technique is then used to discriminate between signal and background events. Events from  $WWW$  production are observed with a significance of 8.0 standard deviations, where the expectation is 5.4 standard deviations. The inclusive  $WWW$  production cross section is measured to be  $820 \pm 100$  (stat)  $\pm 80$  (syst) fb, approximately 2.6 standard deviations from the predicted cross section of  $511 \pm 18$  fb calculated at next-to-leading-order QCD and leading-order electroweak accuracy.

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Measurements of triboson production at colliders directly probe the strength of gauge boson self-interactions within the standard model (SM) via triple gauge couplings and quartic gauge couplings [1,2]. Any significant deviations from the SM predictions would provide evidence of new physics at a higher energy scale than is presently accessible [3–8]. Triboson final states are among the least-understood SM processes due to their small production cross sections. In particular, searches for the production of three  $W$  bosons ( $WWW$ ) have been performed by both the ATLAS [9,10] and CMS [11,12] Collaborations. Using proton-proton ( $pp$ ) collisions at a center-of-mass energy ( $\sqrt{s}$ ) of 13 TeV delivered by the Large Hadron Collider (LHC) [13], the ATLAS Collaboration analyzed  $80 \text{ fb}^{-1}$  of data and provided evidence for both  $WWW$  and  $WWZ/WZZ$  production [10], and the CMS Collaboration analyzed  $137 \text{ fb}^{-1}$  of data and observed the combined production of three massive vector bosons ( $WWW$ ,  $WWZ$ ,  $WZZ$ , and  $ZZZ$ ) [12].

This Letter reports the observation of  $WWW$  production and a measurement of its cross section using  $139 \text{ fb}^{-1}$  of data at  $\sqrt{s} = 13$  TeV [14] taken with the ATLAS detector. At leading order (LO) in QCD,  $WWW$  production can proceed via the radiation of each  $W$  boson from a fermion, via a  $W$  boson produced in association with an intermediate  $Z/\gamma^*$  or Higgs boson that decays via the  $WW^*$  intermediate state, or via a quartic gauge coupling vertex. Representative

Feynman diagrams are shown in Fig. 1. The analysis selection is sensitive to processes with both on-shell and off-shell  $W$  boson decays. For simplicity all these processes (including  $WH \rightarrow WWW^*$ ) are generically referred to as  $WWW$  throughout this Letter. Two decay channels,  $WWW \rightarrow \ell^\pm \nu \ell^\pm \nu qq$  and  $WWW \rightarrow \ell^\pm \nu \ell^\pm \nu \ell^\mp \nu$  with  $\ell = e$  or  $\mu$ , are considered and are hereafter referred to as  $2\ell$  and  $3\ell$ , respectively. Events with electrons and muons produced through  $\tau$  leptons are also included. The experimental signature of the  $2\ell$  channel consists of two same-sign charged leptons, missing transverse momentum, and two jets, while the signature of the  $3\ell$  channel consists of three charged leptons and missing transverse momentum.

The ATLAS detector [15] is a multipurpose particle physics detector with cylindrical geometry [16]. It consists of an inner tracker (ID) surrounded by a superconducting solenoid, sampling electromagnetic (EM) and hadronic calorimeters, and a muon spectrometer (MS) with three toroidal superconducting magnets. A two-level trigger system is used to select events for storage. Events used in this analysis were selected online by single-electron or single-muon triggers [17–19]. An extensive software suite [20] is used in the reconstruction and analysis of real and simulated data, in detector operations, and in the trigger and data acquisition systems of the experiment.

The proton interaction vertex with the highest  $p_T^2$  sum of associated ID tracks is selected as the primary vertex. Electrons are reconstructed from energy deposits in the EM calorimeter associated with tracks found in the ID. Muons are reconstructed by combining tracks reconstructed in the ID with tracks or track segments found in the MS. Electrons (muons) must have  $p_T > 20$  GeV and be reconstructed within  $|\eta| < 2.47$  ( $|\eta| < 2.5$ ), excluding electrons within

\*Full author list given at the end of the Letter.

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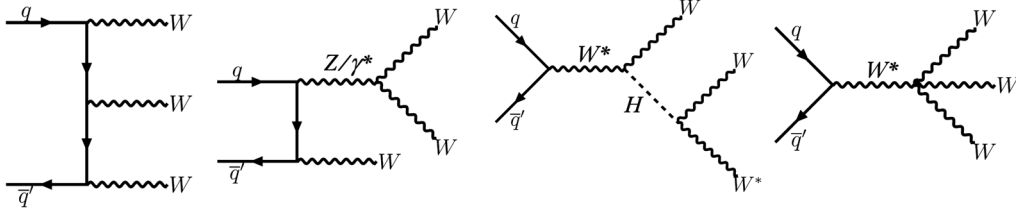


FIG. 1. Representative Feynman diagrams at LO for the production of three massive  $W$  bosons, including diagrams sensitive to triple and quartic gauge couplings.

$1.37 < |\eta| < 1.52$ . To ensure that selected leptons originate from the primary vertex, their tracks are required to have  $|d_0/\sigma_{d_0}| < 5(3)$  for electrons (muons) and  $|z_0 \sin \theta| < 0.5$  mm for both lepton flavors, where  $d_0$  and  $\sigma_{d_0}$  are the transverse impact parameter and its uncertainty, and  $z_0$  is the longitudinal impact parameter. Electrons are required to satisfy the “tight” likelihood-based identification criterion defined in Ref. [21], and muons must satisfy the “medium” cut-based identification criterion defined in Ref. [22]. To reject leptons that likely originate from light-hadron decays or heavy-flavor decays, leptons are required to pass a tight isolation requirement (“PLVTight”) [23], which takes into account the energy deposits and charged-particle tracks (including the lepton track) in a cone around the lepton direction. Electrons must also satisfy a charge identification criterion based on a boosted decision tree (BDT) discriminant [24] to reduce the contamination from electrons with misidentified electric charge.

Particle-flow jets are reconstructed from tracks in the ID and topological energy clusters in the calorimeter [25]. Jet candidates are required to have  $p_T > 30$  GeV in the forward region ( $2.5 < |\eta| < 4.5$ ) and  $p_T > 20$  GeV in the central region ( $|\eta| < 2.5$ ). To reduce the effect from additional  $pp$  collisions in the same or a nearby bunch crossing (pileup), jets with  $20 \text{ GeV} < p_T < 60$  GeV and  $|\eta| < 2.5$  are required to pass a “jet vertex tagger” requirement [26]. Jets containing  $b$ -flavored hadrons (“ $b$  jets”) are identified by a multivariate discriminant [27,28] combining track impact parameter values with information from secondary vertices reconstructed within the jet. A working point corresponding to an 85% efficiency for identifying  $b$  jets in  $t\bar{t}$  events is used. Procedures described in Ref. [10] that ensure the selected electron, muon, and jet candidates do not overlap are applied before the lepton “PLVTight” and  $|d_0/\sigma_{d_0}|$  requirements.

The missing transverse momentum, whose magnitude is denoted by  $E_T^{\text{miss}}$ , is calculated as the negative of the vector sum of the transverse momenta of all reconstructed objects associated with the primary vertex. To account for soft hadronic activity, a term including tracks associated with the primary vertex but not with any of the reconstructed objects is included in the calculation of  $E_T^{\text{miss}}$  [29].

To select candidates in the  $2\ell$  signal regions (SRs), events are required to have exactly two leptons with the

same electric charge, at least two central jets, and no identified  $b$  jets. Three final states based on the lepton flavors are considered, namely  $e^\pm e^\pm$ ,  $e^\pm \mu^\pm$ , and  $\mu^\pm \mu^\pm$ . The highest- $p_T$  lepton must have  $p_T > 27$  GeV and the dilepton invariant mass  $m_{\ell\ell}$  is required to be between 40 and 400 GeV. The two highest- $p_T$  central jets are required to have  $m_{jj} < 160$  GeV and  $|\Delta\eta_{jj}| < 1.5$ , where  $m_{jj}$  is the dijet invariant mass and  $\Delta\eta_{jj}$  is the pseudorapidity separation between the two jets. The  $m_{jj}$  and  $\Delta\eta_{jj}$  selection suppresses contributions from the  $W^\pm W^\pm$  vector-boson scattering process. In the case of the  $e^\pm e^\pm$  final state, the dilepton system is required to have  $m_{\ell\ell} < 80$  GeV or  $m_{\ell\ell} > 100$  GeV and an  $E_T^{\text{miss}}$  significance [30] requirement,  $\mathcal{S}(E_T^{\text{miss}}) > 3$ , is applied to suppress contributions from the  $Z + \text{jets}$  process where the charge of one electron is misidentified. To select candidates in the  $3\ell$  SR, events are required to have exactly three leptons including at least one with  $p_T > 27$  GeV, no identified  $b$  jets, and no same-flavor opposite-sign (SFOS) lepton pairs. Events with  $e^\pm e^\pm \mu^\mp$  and  $\mu^\pm \mu^\pm e^\mp$  final states are considered. To suppress contributions from  $WZ + \text{jets}$  production in the  $2\ell$  SRs and  $ZZ + \text{jets}$  production in the  $3\ell$  SR, events are removed if they contain additional electrons (muons) reconstructed with  $p_T > 7(4.5)$  GeV and  $|\eta| < 2.47(2.7)$  passing the loose [21] ([22]) identification requirement.

Monte Carlo (MC) simulated samples are used to model the signal  $WWW$  process, as well as contributions from other physics processes with prompt leptons. Simulated events were processed through the full ATLAS detector simulation [31] based on GEANT4 [32]. The effects of pileup are included in the simulation.

Events with three on-shell  $W$  bosons were generated by SHERPA2.2.2 [33,34] with the NNPDF3.0NNLO parton distribution function (PDF) [35]. Events with an off-shell  $W$  boson through  $WH \rightarrow WWW^*$  were generated using POWHEG BOXv2 [36] interfaced to PYTHIA8.235 [37] for parton showering [38] with the NNPDF2.3LO PDF and the AZNLO set of tuned parameters [39]. Both processes are included in the signal definition and were generated at next-to-leading-order (NLO) QCD accuracy and LO electro-weak accuracy with all spin correlations taken into account in the vector-boson decays. The cross section for the process with on-shell (off-shell  $WH \rightarrow WWW^*$ )  $W$  bosons is  $209 \pm 17$  fb ( $302 \pm 8$  fb). The inclusive cross section is

$\sigma^{\text{pred}}(pp \rightarrow WWW) = 511 \pm 18$  fb. The cross sections and uncertainties used in this analysis are consistent with the latest calculations with NLO QCD and NLO electroweak corrections applied for the on-shell  $WWW$  process [40] and with next-to-next-to-next-to-leading-order (NNNLO) QCD and NLO electroweak corrections applied for the  $WH \rightarrow WWW^*$  process [41].

The dominant background originates from the  $\ell\nu\ell\ell + \text{jets}(WZ + \text{jets})$  process, and its contribution is estimated using simulated events generated with SHERPA2.2.2 using the NNPDF3.0NNLO PDF and a threshold of 4 GeV on the  $Z$  boson mass. The matrix element calculations for the  $WZ$  process were performed with up to one additional parton at NLO QCD accuracy and up to three additional partons at LO QCD accuracy. To ensure proper modeling of the  $WZ$  background, the MC predictions for  $WZ + 0$  jets,  $WZ + 1$  jet, and  $WZ + \geq 2$  jets are multiplied by scale factors obtained during the fit to the data to be described later, which includes three  $WZ$  control regions (CR). These CRs are obtained by requiring exactly three leptons with one SFOS lepton pair,  $E_T^{\text{miss}}$  significance  $\mathcal{S}(E_T^{\text{miss}}) > 3$ , no  $b$  jets identified, and a trilepton invariant mass  $110 \text{ GeV} < m_{\ell\ell\ell} < 500 \text{ GeV}$ .

The contribution from backgrounds with nonprompt leptons from hadron (including  $b$ -flavored and  $c$ -flavored hadrons) decays and jets misidentified as leptons is estimated using a data-driven method described in Ref. [42]. Lepton-like jets are defined by requiring the leptons to meet a looser selection criterion but fail the signal-lepton requirements. Compared to signal leptons, muonlike jets have  $|d_0/\sigma_{d_0}| < 10$ , and electronlike jets have the likelihood-based identification criterion loosened to “medium” [21]. The PLVTight tight isolation criterion is dropped for both lepton flavors. Since the nonprompt-lepton background in the SRs comes mainly from the  $t\bar{t}$  process where one of the  $b$  jets is misidentified as an isolated lepton, a lepton “fake factor” is determined from  $t\bar{t}$ -enriched samples selected using the same signal region criteria, except requiring one  $b$  jet and, in the  $3\ell$  case, including events with a SFOS lepton pair with  $m_{\ell\ell} < 80 \text{ GeV}$  or  $m_{\ell\ell} > 100 \text{ GeV}$ . To estimate the nonprompt-lepton background, this fake factor is applied as a weight to events selected with the same set of criteria as the signal region but with a leptonlike jet. The nonprompt-lepton background estimate is validated by checking that the estimate agrees with the data in the  $t\bar{t}$ -enriched samples where the fake factors are measured.

The  $W\gamma/Z\gamma$  background mostly contributes to the event selection when the photon is being misidentified as an electron. This contribution (referred to as “ $\gamma$  conversions”) is evaluated using a data-driven method similar to the nonprompt-lepton background estimation by introducing electronlike photons. An electronlike photon is a reconstructed object that is like an electron except that its associated track has no hits in the innermost layer of the

pixel detector. The photon fake factor is determined using  $Z\gamma \rightarrow \mu\mu\gamma$  events selected with two muons, no  $b$  jets, and one electron or one electronlike photon. The trilepton invariant mass must satisfy  $80 \text{ GeV} < m_{e\mu\mu} < 100 \text{ GeV}$ .

The charge-flip background originates from processes in which the charge of at least one prompt electron is misidentified. The muon charge misidentification rate is found to be negligible. The electron charge misidentification rate is measured using a tag-and-probe method applied to  $Z \rightarrow e^+e^-$  events, where the two electrons have the same reconstructed charge [42]. The charge-flip background is estimated by applying the measured electron charge misidentification rates to  $e^\pm e^\pm$ ,  $e^\pm \mu^\pm$ , and  $e^\pm e^\pm \mu^\mp$  data events that meet all signal region requirements except for the SFOS lepton pair veto requirement. This method is validated with events selected using the same set of signal region criteria as used in the  $e^\pm e^\pm$  final state, except the dilepton mass must satisfy  $80 \text{ GeV} < m_{\ell\ell} < 100 \text{ GeV}$  and the  $E_T^{\text{miss}}$  significance requirement  $\mathcal{S}(E_T^{\text{miss}}) > 3$  is removed.

Other SM processes with prompt leptons include  $t\bar{t}W$ ,  $t\bar{t}Z$ ,  $tZq$ ,  $t\bar{t}H$ ,  $WWZ$ ,  $WZZ$ ,  $ZZZ$ , and  $W^\pm W^\pm jj$  production. Their contributions are estimated using simulated events normalized to the integrated luminosity of the data sample and the cross sections provided by the event generators. The  $t\bar{t}W$ ,  $t\bar{t}Z$ , and  $tZq$  processes were modeled using MADGRAPH5\_AMC@NLO2.3.3 [43] together with PYTHIA8.210, with up to two additional partons in the matrix-element calculations. The  $t\bar{t}H$  process was modeled using POWHEG BOX v2 interfaced with PYTHIA8.230. Other triboson processes ( $WWZ$ ,  $WZZ$ ,  $ZZZ$ ) and the strong production of  $W^\pm W^\pm jj$  were modeled using SHERPA2.2.2. The calculations for triboson processes were performed with no extra partons at NLO QCD accuracy and up to two additional partons at LO QCD accuracy. The electroweak production of  $W^\pm W^\pm jj$  was modeled using SHERPA2.2.11, and the calculations were performed with up to one additional parton at LO QCD accuracy. Contributions from the on-shell  $WWW$  and  $WH \rightarrow WWW^*$  processes were removed from  $W^\pm W^\pm jj$  production. Contributions from double parton scattering processes are found to be negligible.

To improve the separation between signal and background, two BDTs are trained using the XGBoost [44] package and are applied separately to the  $2\ell$  and  $3\ell$  SRs. All backgrounds are included in the BDT training. Each BDT is trained with 11 variables, some of which differ between the two sets. The three variables with the highest discriminating power are  $|m_{jj} - m_W|$ , where  $m_W$  is the pole mass of the  $W$  boson, forward jet  $p_T$ , and  $\mathcal{S}(E_T^{\text{miss}})$  for the  $2\ell$  channel, and the ratio  $\mathcal{S}(E_T^{\text{miss}})/E_T^{\text{miss}}$ ,  $p_T$  of the second highest- $p_T$  lepton, and number of jets for the  $3\ell$  channel. A  $k$ -fold cross-validation procedure is used to produce the final discriminant. Fivefold (fourfold) cross-validation BDTs are trained in the  $2\ell$  SRs ( $3\ell$  SR) and each BDT is trained on 80% (75%) of the expected signal and

TABLE I. Number of events for postfit signal, background, and data observed in the  $2\ell$  and  $3\ell$  SRs. The uncertainties shown include both the statistical and systematic contributions.

	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$	$3\ell$
WWW signal	$28.4 \pm 4.3$	$124 \pm 19$	$82 \pm 12$	$34.8 \pm 5.2$
WZ	$81.1 \pm 5.7$	$346 \pm 22$	$170 \pm 10$	$16.4 \pm 1.5$
Charge-flip	$31.1 \pm 7.3$	$19 \pm 5$	...	$1.7 \pm 0.4$
$\gamma$ conversions	$60.8 \pm 8.5$	$139 \pm 15$	...	$1.5 \pm 0.1$
Nonprompt	$17.0 \pm 4.0$	$145 \pm 23$	$104 \pm 21$	$26.6 \pm 2.9$
Other	$22.3 \pm 2.4$	$100 \pm 10$	$58 \pm 6$	$8.0 \pm 0.9$
Total predicted	$241 \pm 11$	$873 \pm 22$	$415 \pm 17$	$89.0 \pm 5.4$
Data	242	885	418	79

background events. To produce the BDT distribution used in the fit, each of the five (four) trained BDTs is applied to the 20% (25%) of the events not used to train the BDTs.

To extract the  $WWW$  inclusive cross section, a binned maximum likelihood fit [45] is performed using the BDT distributions in the  $2\ell$  SRs ( $e^\pm e^\pm$ ,  $e^\pm \mu^\pm$ , and  $\mu^\pm \mu^\pm$ ) and the  $3\ell$  SR as well as the  $m_{\ell\ell\ell}$  distributions in the three  $WZ$  CRs, amounting to seven distributions with 50 bins in total. The fit includes four unconstrained parameters that scale the number of events for a particular process predicted by MC simulation: the signal strength  $\mu(WWW)$  for  $WWW$  production and three scale factors for  $WZ + 0$  jets,  $WZ + 1$  jet, and  $WZ + \geq 2$  jets. The ratio of on-shell  $WWW$  production to  $WH \rightarrow WWW^*$  production is determined from MC simulation and is allowed to vary within the theoretical uncertainties of the two processes.

Systematic uncertainties are included in the fit as nuisance parameters constrained by Gaussian probability density functions. Correlations between systematic uncertainties arising from common sources are maintained across processes and channels. Instrumental systematic uncertainties are related to the lepton trigger, reconstruction and

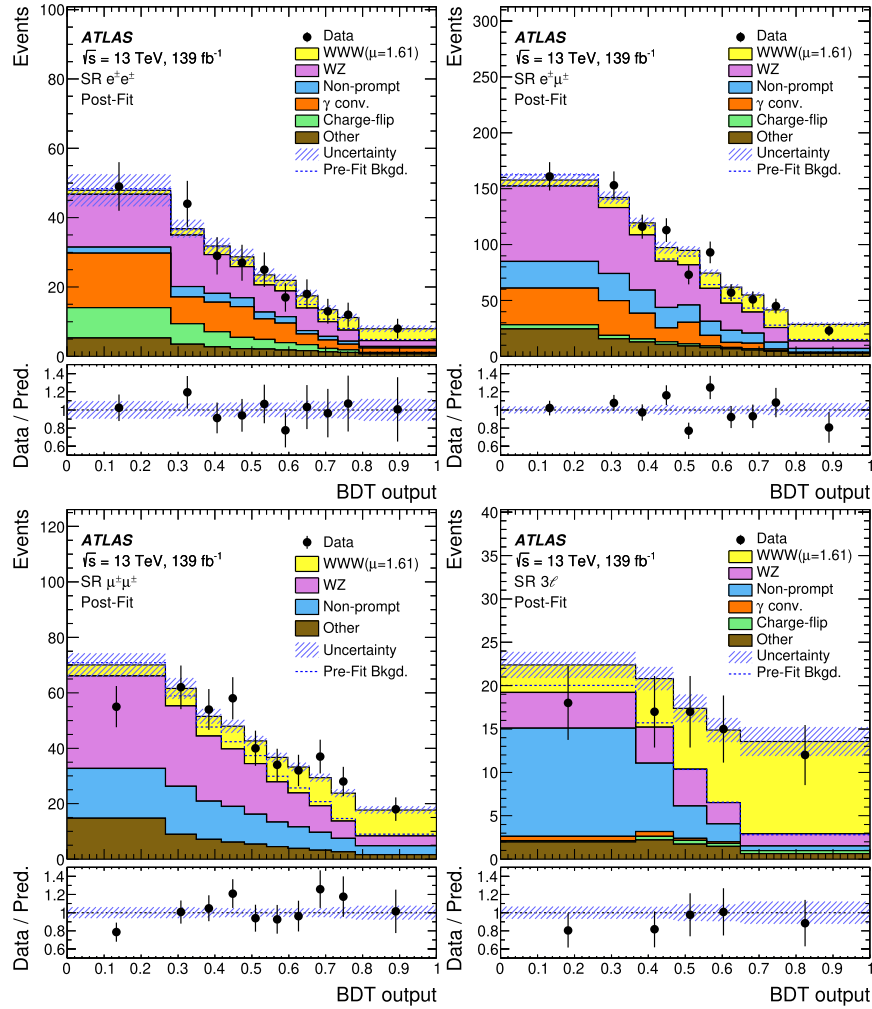


FIG. 2. Postfit BDT output distribution in the  $e^\pm e^\pm$  (top left),  $e^\pm \mu^\pm$  (top right),  $\mu^\pm \mu^\pm$  (bottom left), and  $3\ell$  (bottom right) channels. The bottom panel of each plot shows the ratio of the data to the total prediction. The uncertainty bands include both the statistical and systematic uncertainties as obtained by the fit. The signal is scaled to the fitted signal strength of 1.61.

identification efficiencies [22,24], lepton isolation criteria [23], lepton energy scale and resolution [22,46], jet energy scale and resolution [47], jet vertex tagging [48,49],  $b$ -jet identification [27], modeling of  $E_T^{\text{miss}}$  [50] and pileup, and integrated luminosity [14,51]. Theoretical uncertainties associated with the signal processes and the background processes with prompt leptons are evaluated using simulation. For the signal and  $WZ$  background, acceptance and distribution shape uncertainties due to the renormalization and factorization scales [52], PDFs [53], and parton showering, are also included in the simultaneous fit. The normalization uncertainties for the processes included in the “Other” background category in Table I and Fig. 2 are between 10% and 20% [54–57]. The fit includes the systematic uncertainties of each of the data-driven background estimates, and also the systematic uncertainties due to limited MC sample size.

The signal strength is measured to be  $\mu(WWW) = 1.61 \pm 0.25$ , where the uncertainty also includes the signal cross-section uncertainty (3.6%) affecting the predicted inclusive cross section from the signal MC samples. The three  $WZ$  scale factors are found to be  $1.12 \pm 0.11$ ,  $0.98 \pm 0.04$ , and  $0.88 \pm 0.18$  for the 0-jet, 1-jet, and  $\geq 2$ -jet bins. Table I shows the postfit signal and background event yields as well as the observed yield in each SR. The contribution of the  $WH$  process to the  $WWW$  yield ranges between 40% and 44% in the four SRs. All nuisance parameters remain within their one standard deviation uncertainty after the fit. Figure 2 shows a comparison between data and postfit predictions for the BDT output score distribution in all SRs. For various postfit kinematic distributions in the SRs, data and predictions are found to have a  $p$  value greater than 0.05 from a  $\chi^2$  test that takes into account the systematic uncertainties and correlations used in the fit to data.

The background-only hypothesis is rejected with an observed (expected) significance of 6.6 (4.0) standard deviations for the  $2\ell$  SRs and 4.8 (3.8) standard deviations for the  $3\ell$  SR calculated using the asymptotic approximation [58]. The combined observed (expected) significance is found to be 8.0 (5.4) standard deviations, constituting the first observation of  $WWW$  production. The signal strength is also measured separately by fitting the BDT distribution in each SR with the three  $WZ$  CRs. The values are found to be consistent:  $1.54 \pm 0.76$  for  $e^\pm e^\pm$ ,  $1.44 \pm 0.39$  for  $e^\pm \mu^\pm$ ,  $2.23 \pm 0.46$  for  $\mu^\pm \mu^\pm$ , and  $1.32 \pm 0.39$  for  $3\ell$ .

The measured inclusive  $pp \rightarrow WWW$  production cross section is calculated as the product of the measured signal strength and the cross section from MC simulation, and is found to be  $\sigma^{\text{meas}}(pp \rightarrow WWW) = 820 \pm 100$  (stat)  $\pm 80$  (syst) fb. The largest systematic uncertainty contribution is 6% from data-driven estimates (mainly nonprompt background), followed by 3% from prompt-lepton-background modeling uncertainties (primarily  $WZ$  theory uncertainties).

In conclusion, the first observation of the  $pp \rightarrow WWW$  process is reported by the ATLAS experiment at the LHC. Events with two same-sign charged leptons in association with at least two jets, as well as events with three charged leptons and no same-flavor opposite-sign lepton pairs, were selected from  $139 \text{ fb}^{-1}$  of 13 TeV  $pp$  collisions. Two BDTs were trained to improve the separation between signal and background. The SM background-only hypothesis is rejected with an observed (expected) significance of 8.0 (5.4) standard deviations. The inclusive  $pp \rightarrow WWW$  production cross section is measured to be  $820 \pm 100$  (stat)  $\pm 80$  (syst) fb, approximately 2.6 standard deviations from the predicted cross section of  $511 \pm 18$  fb calculated at NLO QCD and LO electroweak accuracy.

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 S. Bressler,<sup>176</sup> B. Brickwedde,<sup>98</sup> D. Britton,<sup>57</sup> D. Britzger,<sup>113</sup> I. Brock,<sup>24</sup> G. Brooijmans,<sup>39</sup> W. K. Brooks,<sup>144f</sup> E. Brost,<sup>29</sup>  
 P. A. Bruckman de Renstrom,<sup>84</sup> B. Brüers,<sup>46</sup> D. Bruncko,<sup>28b</sup> A. Bruni,<sup>23b</sup> G. Bruni,<sup>23b</sup> M. Bruschi,<sup>23b</sup> N. Bruscino,<sup>72a,72b</sup>  
 L. Bryngemark,<sup>150</sup> T. Buanes,<sup>16</sup> Q. Buat,<sup>145</sup> P. Buchholz,<sup>148</sup> A. G. Buckley,<sup>57</sup> I. A. Budagov,<sup>79</sup> M. K. Bugge,<sup>131</sup>  
 O. Bulekov,<sup>110</sup> B. A. Bullard,<sup>59</sup> S. Burdin,<sup>90</sup> C. D. Burgard,<sup>46</sup> A. M. Burger,<sup>127</sup> B. Burghgrave,<sup>8</sup> J. T. P. Burr,<sup>32</sup>  
 C. D. Burton,<sup>11</sup> J. C. Burzynski,<sup>149</sup> E. L. Busch,<sup>39</sup> V. Büscher,<sup>98</sup> P. J. Bussey,<sup>57</sup> J. M. Butler,<sup>25</sup> C. M. Buttar,<sup>57</sup>  
 J. M. Butterworth,<sup>94</sup> W. Buttinger,<sup>141</sup> C. J. Buxo Vazquez,<sup>105</sup> A. R. Buzykaev,<sup>119b,119a</sup> G. Cabras,<sup>23b</sup> S. Cabrera Urbán,<sup>170</sup>  
 D. Caforio,<sup>56</sup> H. Cai,<sup>136</sup> V. M. M. Cairo,<sup>150</sup> O. Cakir,<sup>3a</sup> N. Calace,<sup>36</sup> P. Calafiura,<sup>17</sup> G. Calderini,<sup>133</sup> P. Calfayan,<sup>65</sup> G. Callea,<sup>57</sup>  
 L. P. Caloba,<sup>80b</sup> D. Calvet,<sup>38</sup> S. Calvet,<sup>38</sup> T. P. Calvet,<sup>100</sup> M. Calvetti,<sup>71a,71b</sup> R. Camacho Toro,<sup>133</sup> S. Camarda,<sup>36</sup>  
 D. Camarero Munoz,<sup>97</sup> P. Camarri,<sup>73a,73b</sup> M. T. Camerlingo,<sup>74a,74b</sup> D. Cameron,<sup>131</sup> C. Camincher,<sup>172</sup> M. Campanelli,<sup>94</sup>  
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 A. Carbone,<sup>68a,68b</sup> R. Cardarelli,<sup>73a</sup> J. C. J. Cardenas,<sup>8</sup> F. Cardillo,<sup>170</sup> G. Carducci,<sup>41b,41a</sup> T. Carli,<sup>36</sup> G. Carlino,<sup>69a</sup>  
 B. T. Carlson,<sup>136</sup> E. M. Carlson,<sup>172,164a</sup> L. Carminati,<sup>68a,68b</sup> M. Carnesale,<sup>72a,72b</sup> S. Caron,<sup>116</sup> E. Carquin,<sup>144f</sup> S. Carrá,<sup>46</sup>

G. Carratta,<sup>23b,23a</sup> J. W. S. Carter,<sup>163</sup> T. M. Carter,<sup>50</sup> D. Casadei,<sup>33c</sup> M. P. Casado,<sup>13j</sup> A. F. Casha,<sup>163</sup> E. G. Castiglia,<sup>179</sup>  
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 A. S. Cerqueira,<sup>80a</sup> A. Cerri,<sup>153</sup> L. Cerrito,<sup>73a,73b</sup> F. Cerutti,<sup>17</sup> A. Cervelli,<sup>23b</sup> S. A. Cetin,<sup>21d</sup> Z. Chadi,<sup>35a</sup> D. Chakraborty,<sup>118</sup>  
 M. Chala,<sup>137f</sup> J. Chan,<sup>177</sup> W. S. Chan,<sup>117</sup> W. Y. Chan,<sup>90</sup> J. D. Chapman,<sup>32</sup> B. Chargeishvili,<sup>156b</sup> D. G. Charlton,<sup>20</sup>  
 T. P. Charman,<sup>92</sup> M. Chatterjee,<sup>19</sup> S. Chekanov,<sup>6</sup> S. V. Chekulaev,<sup>164a</sup> G. A. Chelkov,<sup>79,k</sup> A. Chen,<sup>104</sup> B. Chen,<sup>158</sup> B. Chen,<sup>172</sup>  
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 C. L. Cheng,<sup>177</sup> H. C. Cheng,<sup>62a</sup> A. Cheplakov,<sup>79</sup> E. Cheremushkina,<sup>46</sup> E. Cherepanova,<sup>79</sup> R. Cherkaoui El Moursli,<sup>35e</sup>  
 E. Cheu,<sup>7</sup> K. Cheung,<sup>63</sup> L. Chevalier,<sup>142</sup> V. Chiarella,<sup>51</sup> G. Chiarelli,<sup>71a</sup> G. Chiodini,<sup>67a</sup> A. S. Chisholm,<sup>20</sup> A. Chitan,<sup>27b</sup>  
 Y. H. Chiu,<sup>172</sup> M. V. Chizhov,<sup>79</sup> K. Choi,<sup>11</sup> A. R. Chomont,<sup>72a,72b</sup> Y. Chou,<sup>101</sup> E. Y. S. Chow,<sup>117</sup> T. Chowdhury,<sup>33g</sup>  
 L. D. Christopher,<sup>33g</sup> M. C. Chu,<sup>62a</sup> X. Chu,<sup>14a,14d</sup> J. Chudoba,<sup>138</sup> J. J. Chwastowski,<sup>84</sup> D. Cieri,<sup>113</sup> K. M. Ciesla,<sup>84</sup>  
 V. Cindro,<sup>91</sup> A. Ciochio,<sup>17</sup> F. Ciroto,<sup>69a,69b</sup> Z. H. Citron,<sup>176,l</sup> M. Citterio,<sup>68a</sup> D. A. Ciubotaru,<sup>27b</sup> B. M. Ciungu,<sup>163</sup> A. Clark,<sup>54</sup>  
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 A. Coccaro,<sup>55b</sup> R. F. Coelho Barrue,<sup>137a</sup> R. Coelho Lopes De Sa,<sup>101</sup> S. Coelli,<sup>68a</sup> H. Cohen,<sup>158</sup> A. E. C. Coimbra,<sup>36</sup> B. Cole,<sup>39</sup>  
 J. Collot,<sup>58</sup> P. Conde Muiño,<sup>137a,137g</sup> S. H. Connell,<sup>33c</sup> I. A. Connelly,<sup>57</sup> E. I. Conroy,<sup>132</sup> F. Conventi,<sup>69a,m</sup> H. G. Cooke,<sup>20</sup>  
 A. M. Cooper-Sarkar,<sup>132</sup> F. Cormier,<sup>171</sup> L. D. Corpe,<sup>36</sup> M. Corradi,<sup>72a,72b</sup> E. E. Corrigan,<sup>96</sup> F. Corriveau,<sup>102,n</sup> M. J. Costa,<sup>170</sup>  
 F. Costanza,<sup>4</sup> D. Costanzo,<sup>146</sup> B. M. Cote,<sup>125</sup> G. Cowan,<sup>93</sup> J. W. Cowley,<sup>32</sup> K. Cranmer,<sup>123</sup> S. Crépe-Renaudin,<sup>58</sup>  
 F. Crescioli,<sup>133</sup> M. Cristinziani,<sup>148</sup> M. Cristoforetti,<sup>75a,75b,o</sup> V. Croft,<sup>166</sup> G. Crosetti,<sup>41b,41a</sup> A. Cueto,<sup>36</sup>  
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 P. Czodrowski,<sup>36</sup> M. M. Czurylo,<sup>61b</sup> M. J. Da Cunha Sargedas De Sousa,<sup>60a</sup> J. V. Da Fonseca Pinto,<sup>80b</sup> C. Da Via,<sup>99</sup>  
 W. Dabrowski,<sup>83a</sup> T. Dado,<sup>47</sup> S. Dahbi,<sup>33g</sup> T. Dai,<sup>104</sup> C. Dallapiccola,<sup>101</sup> M. Dam,<sup>40</sup> G. D'amen,<sup>29</sup> V. D'Amico,<sup>74a,74b</sup>  
 J. Damp,<sup>98</sup> J. R. Dandoy,<sup>134</sup> M. F. Daneri,<sup>30</sup> M. Danninger,<sup>149</sup> V. Dao,<sup>36</sup> G. Darbo,<sup>55b</sup> S. Darmora,<sup>6</sup> A. Dattagupta,<sup>129</sup>  
 S. D'Auria,<sup>68a,68b</sup> C. David,<sup>164b</sup> T. Davidek,<sup>140</sup> D. R. Davis,<sup>49</sup> B. Davis-Purcell,<sup>34</sup> I. Dawson,<sup>92</sup> K. De,<sup>8</sup> R. De Asmundis,<sup>69a</sup>  
 M. De Beurs,<sup>117</sup> S. De Castro,<sup>23b,23a</sup> N. De Groot,<sup>116</sup> P. de Jong,<sup>117</sup> H. De la Torre,<sup>105</sup> A. De Maria,<sup>14c</sup> A. De Salvo,<sup>72a</sup>  
 U. De Sanctis,<sup>73a,73b</sup> M. De Santis,<sup>73a,73b</sup> A. De Santo,<sup>153</sup> J. B. De Vivie De Regie,<sup>58</sup> D. V. Dedovich,<sup>79</sup> J. Degens,<sup>117</sup>  
 A. M. Deiana,<sup>42</sup> J. Del Peso,<sup>97</sup> F. Del Rio,<sup>61a</sup> F. Deliot,<sup>142</sup> C. M. Delitzsch,<sup>47</sup> M. Della Pietra,<sup>69a,69b</sup> D. Della Volpe,<sup>54</sup>  
 A. Dell'Acqua,<sup>36</sup> L. Dell'Asta,<sup>68a,68b</sup> M. Delmastro,<sup>4</sup> P. A. Delsart,<sup>58</sup> S. Demers,<sup>179</sup> M. Demichev,<sup>79</sup> S. P. Denisov,<sup>120</sup>  
 L. D'Eramo,<sup>118</sup> D. Derendarz,<sup>84</sup> F. Derue,<sup>133</sup> P. Dervan,<sup>90</sup> K. Desch,<sup>24</sup> K. Dette,<sup>163</sup> C. Deutsch,<sup>24</sup> P. O. Deviveiros,<sup>36</sup>  
 F. A. Di Bello,<sup>72a,72b</sup> A. Di Ciaccio,<sup>73a,73b</sup> L. Di Ciaccio,<sup>4</sup> A. Di Domenico,<sup>72a,72b</sup> C. Di Donato,<sup>69a,69b</sup> A. Di Girolamo,<sup>36</sup>  
 G. Di Gregorio,<sup>71a,71b</sup> A. Di Luca,<sup>75a,75b,o</sup> B. Di Micco,<sup>74a,74b</sup> R. Di Nardo,<sup>74a,74b</sup> C. Diaconu,<sup>100</sup> F. A. Dias,<sup>117</sup>  
 T. Dias Do Vale,<sup>149</sup> M. A. Diaz,<sup>144a</sup> F. G. Diaz Capriles,<sup>24</sup> M. Didenko,<sup>170</sup> E. B. Diehl,<sup>104</sup> S. Díez Cornell,<sup>46</sup>  
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 F. Dittus,<sup>36</sup> F. Djama,<sup>100</sup> T. Djobava,<sup>156b</sup> J. I. Djuvsland,<sup>16</sup> D. Dodsworth,<sup>26</sup> C. Doglioni,<sup>99,96</sup> J. Dolejsi,<sup>140</sup> Z. Dolezal,<sup>140</sup>  
 M. Donadelli,<sup>80c</sup> B. Dong,<sup>60c</sup> J. Donini,<sup>38</sup> A. D'onofrio,<sup>14c</sup> M. D'Onofrio,<sup>90</sup> J. Dopke,<sup>141</sup> A. Doria,<sup>69a</sup> M. T. Dova,<sup>88</sup>  
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 C. Dülsen,<sup>178</sup> A. E. Dumitriu,<sup>27b</sup> M. Dunford,<sup>61a</sup> S. Dungs,<sup>47</sup> K. Dunne,<sup>45a,45b</sup> A. Duperrin,<sup>100</sup> H. Duran Yildiz,<sup>3a</sup> M. Düren,<sup>56</sup>  
 A. Durglishvili,<sup>156b</sup> B. Dutta,<sup>46</sup> B. L. Dwyer,<sup>118</sup> G. I. Dyckes,<sup>17</sup> M. Dyndal,<sup>83a</sup> S. Dysch,<sup>99</sup> B. S. Dziedzic,<sup>84</sup> B. Eckerova,<sup>28a</sup>  
 M. G. Eggleston,<sup>49</sup> E. Egidio Purcino De Souza,<sup>80b</sup> L. F. Ehrke,<sup>54</sup> G. Eigen,<sup>16</sup> K. Einsweiler,<sup>17</sup> T. Ekelof,<sup>168</sup> Y. El Ghazali,<sup>35b</sup>  
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 S. Falciano,<sup>72a</sup> P. J. Falke,<sup>24</sup> S. Falke,<sup>36</sup> J. Faltova,<sup>140</sup> Y. Fan,<sup>14a</sup> Y. Fang,<sup>14a</sup> G. Fanourakis,<sup>44</sup> M. Fanti,<sup>68a,68b</sup> M. Faraj,<sup>60c</sup>  
 A. Farbin,<sup>8</sup> A. Farilla,<sup>74a</sup> E. M. Farina,<sup>70a,70b</sup> T. Farooque,<sup>105</sup> S. M. Farrington,<sup>50</sup> F. Fassi,<sup>35e</sup> D. Fassouliotis,<sup>9</sup>  
 M. Fauci Giannelli,<sup>73a,73b</sup> W. J. Fawcett,<sup>32</sup> L. Fayard,<sup>64</sup> O. L. Fedin,<sup>135,p</sup> G. Fedotov,<sup>135</sup> M. Feickert,<sup>169</sup> L. Feligioni,<sup>100</sup>  
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 J. A. Fernandez Pretel,<sup>52</sup> J. Ferrando,<sup>46</sup> A. Ferrari,<sup>168</sup> P. Ferrari,<sup>117</sup> R. Ferrari,<sup>70a</sup> D. Ferrere,<sup>54</sup> C. Ferretti,<sup>104</sup> F. Fiedler,<sup>98</sup>  
 A. Filipčič,<sup>91</sup> F. Filthaut,<sup>116</sup> M. C. N. Fiolhais,<sup>137a,137c,q</sup> L. Fiorini,<sup>170</sup> F. Fischer,<sup>148</sup> W. C. Fisher,<sup>105</sup> T. Fitschen,<sup>20,64</sup>

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Gee,<sup>143</sup> J. Geisen,<sup>96</sup> M. Geisen,<sup>98</sup> C. Gemme,<sup>55b</sup> M. H. Genest,<sup>58</sup> S. Gentile,<sup>72a,72b</sup> S. George,<sup>93</sup> W. F. George,<sup>20</sup> T. Gerialis,<sup>44</sup> L. O. Gerlach,<sup>53</sup> P. Gessinger-Befurt,<sup>36</sup> M. Ghasemi Bostanabad,<sup>172</sup> A. Ghosh,<sup>167</sup> A. Ghosh,<sup>7</sup> B. Giacobbe,<sup>23b</sup> S. Giagu,<sup>72a,72b</sup> N. Giangiacomi,<sup>163</sup> P. Giannetti,<sup>71a</sup> A. Giannini,<sup>60a</sup> S. M. Gibson,<sup>93</sup> M. Gignac,<sup>143</sup> D. T. Gil,<sup>83b</sup> B. J. Gilbert,<sup>39</sup> D. Gillberg,<sup>34</sup> G. Gilles,<sup>117</sup> N. E. K. Gillwald,<sup>46</sup> L. Ginabat,<sup>133</sup> D. M. Gingrich,<sup>2,f</sup> M. P. Giordani,<sup>66a,66c</sup> P. F. Giraud,<sup>142</sup> G. Giugliarelli,<sup>66a,66c</sup> D. Giugni,<sup>68a</sup> F. Giuli,<sup>73a,73b</sup> I. Gkialas,<sup>9,r</sup> P. Gkoutoumis,<sup>10</sup> L. K. Gladilin,<sup>111</sup> C. 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G. Jarlskog,<sup>96</sup> A. E. Jaspán,<sup>90</sup> T. Javůrek,<sup>36</sup> M. Javurkova,<sup>101</sup> F. Jeanneau,<sup>142</sup> L. Jeanty,<sup>129</sup> J. Jejelava,<sup>156a,aa</sup> P. Jenni,<sup>52,bb</sup>  
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J. Jovicevic,<sup>15</sup> X. Ju,<sup>17</sup> J. J. Junggeburth,<sup>36</sup> A. Juste Rozas,<sup>13,u</sup> S. Kabana,<sup>144e</sup> A. Kaczmarska,<sup>84</sup> M. Kado,<sup>72a,72b</sup> H. Kagan,<sup>125</sup>  
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A. J. Lankford,<sup>167</sup> F. Lanni,<sup>29</sup> K. Lantsch,<sup>24</sup> A. Lanza,<sup>70a</sup> A. Lapertosa,<sup>55b,55a</sup> J. F. Laporte,<sup>142</sup> T. Lari,<sup>68a</sup>  
F. Lasagni Manghi,<sup>23b</sup> M. Lassnig,<sup>36</sup> V. Latonova,<sup>138</sup> T. S. Lau,<sup>62a</sup> A. Laudrain,<sup>98</sup> A. Laurier,<sup>34</sup> M. Lavorgna,<sup>69a,69b</sup>  
S. D. Lawlor,<sup>93</sup> Z. Lawrence,<sup>99</sup> M. Lazzaroni,<sup>68a,68b</sup> B. Le,<sup>99</sup> B. Leban,<sup>91</sup> A. Lebedev,<sup>78</sup> M. LeBlanc,<sup>36</sup> T. LeCompte,<sup>150</sup>  
F. Ledroit-Guillon,<sup>58</sup> A. C. A. Lee,<sup>94</sup> G. R. Lee,<sup>16</sup> L. Lee,<sup>59</sup> S. C. Lee,<sup>155</sup> L. L. Leeuw,<sup>33c</sup> B. Lefebvre,<sup>164a</sup> H. P. Lefebvre,<sup>93</sup>  
M. Lefebvre,<sup>172</sup> C. Leggett,<sup>17</sup> K. Lehmann,<sup>149</sup> G. Lehmann Miotto,<sup>36</sup> W. A. Leight,<sup>101</sup> A. Leisos,<sup>159,cc</sup> M. A. L. Leite,<sup>80c</sup>  
C. E. Leitgeb,<sup>46</sup> R. Leitner,<sup>140</sup> K. J. C. Leney,<sup>42</sup> T. Lenz,<sup>24</sup> S. Leone,<sup>71a</sup> C. Leonidopoulos,<sup>50</sup> A. Leopold,<sup>151</sup> C. Leroy,<sup>108</sup>  
R. Les,<sup>105</sup> C. G. Lester,<sup>32</sup> M. Levchenko,<sup>135</sup> J. Levêque,<sup>4</sup> D. Levin,<sup>104</sup> L. J. Levinson,<sup>176</sup> D. J. Lewis,<sup>20</sup> B. Li,<sup>14b</sup> B. Li,<sup>60b</sup>  
C. Li,<sup>60a</sup> C-Q. Li,<sup>60c,60d</sup> H. Li,<sup>60a</sup> H. Li,<sup>60b</sup> H. Li,<sup>60b</sup> J. Li,<sup>60c</sup> K. Li,<sup>145</sup> L. Li,<sup>60c</sup> M. Li,<sup>14a,14d</sup> Q. Y. Li,<sup>60a</sup> S. Li,<sup>60d,60c,dd</sup> T. Li,<sup>60b</sup>  
X. Li,<sup>46</sup> Z. Li,<sup>60b</sup> Z. Li,<sup>132</sup> Z. Li,<sup>102</sup> Z. Li,<sup>90</sup> Z. Liang,<sup>14a</sup> M. Liberatore,<sup>46</sup> B. Liberti,<sup>73a</sup> K. Lie,<sup>62c</sup> J. Lieber Marin,<sup>80b</sup> K. Lin,<sup>105</sup>  
R. A. Linck,<sup>65</sup> R. E. Lindley,<sup>7</sup> J. H. Lindon,<sup>2</sup> A. Linss,<sup>46</sup> E. Lipeles,<sup>134</sup> A. Lipniacka,<sup>16</sup> T. M. Liss,<sup>169,ee</sup> A. Lister,<sup>171</sup>  
J. D. Little,<sup>4</sup> B. Liu,<sup>14a</sup> B. X. Liu,<sup>149</sup> D. Liu,<sup>60d,60c</sup> J. B. Liu,<sup>60a</sup> J. K. K. Liu,<sup>32</sup> K. Liu,<sup>60d,60c</sup> M. Liu,<sup>60a</sup> M. Y. Liu,<sup>60a</sup> P. Liu,<sup>14a</sup>  
Q. Liu,<sup>60d,145,60c</sup> X. Liu,<sup>60a</sup> Y. Liu,<sup>46</sup> Y. Liu,<sup>14c,14d</sup> Y. L. Liu,<sup>104</sup> Y. W. Liu,<sup>60a</sup> M. Livan,<sup>70a,70b</sup> J. Llorente Merino,<sup>149</sup>  
S. L. Lloyd,<sup>92</sup> E. M. Lobodzinska,<sup>46</sup> P. Loch,<sup>7</sup> S. Loffredo,<sup>73a,73b</sup> T. Lohse,<sup>18</sup> K. Lohwasser,<sup>146</sup> M. Lokajicek,<sup>138</sup>  
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N. Lorenzo Martinez,<sup>4</sup> A. M. Lory,<sup>112</sup> A. Lösle,<sup>52</sup> X. Lou,<sup>45a,45b</sup> X. Lou,<sup>14a</sup> A. Lounis,<sup>64</sup> J. Love,<sup>6</sup> P. A. Love,<sup>89</sup>  
J. J. Lozano Bahilo,<sup>170</sup> G. Lu,<sup>14a</sup> M. Lu,<sup>77</sup> S. Lu,<sup>134</sup> Y. J. Lu,<sup>63</sup> H. J. Lubatti,<sup>145</sup> C. Luci,<sup>72a,72b</sup> F. L. Lucio Alves,<sup>14c</sup>  
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D. M. Mac Donell,<sup>172</sup> G. Maccarrone,<sup>51</sup> J. C. MacDonald,<sup>146</sup> R. Madar,<sup>38</sup> W. F. Mader,<sup>48</sup> J. Maeda,<sup>82</sup> T. Maeno,<sup>29</sup>  
M. Maerker,<sup>48</sup> V. Magerl,<sup>52</sup> J. Magro,<sup>66a,66c</sup> D. J. Mahon,<sup>39</sup> C. Maidantchik,<sup>80b</sup> A. Maio,<sup>137a,137b,137d</sup> K. Maj,<sup>83a</sup>  
O. Majersky,<sup>28a</sup> S. Majewski,<sup>129</sup> N. Makovec,<sup>64</sup> V. Maksimovic,<sup>15</sup> B. Malaescu,<sup>133</sup> Pa. Malecki,<sup>84</sup> V. P. Maleev,<sup>135</sup>  
F. Malek,<sup>58</sup> D. Malito,<sup>41b,41a</sup> U. Mallik,<sup>77</sup> C. Malone,<sup>32</sup> S. Maltezos,<sup>10</sup> S. Malyukov,<sup>79</sup> J. Mamuzic,<sup>170</sup> G. Mancini,<sup>51</sup>  
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G. Marchiori,<sup>5</sup> M. Marcisovsky,<sup>138</sup> L. Marcoccia,<sup>73a,73b</sup> C. Marcon,<sup>96</sup> M. Marinescu,<sup>20</sup> M. Marjanovic,<sup>126</sup> Z. Marshall,<sup>17</sup>  
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A. C. Martyniuk,<sup>94</sup> A. Marzin,<sup>36</sup> S. R. Maschek,<sup>113</sup> L. Masetti,<sup>98</sup> T. Mashimo,<sup>160</sup> J. Masik,<sup>99</sup> A. L. Maslennikov,<sup>119b,119a</sup>  
L. Massa,<sup>23b</sup> P. Massarotti,<sup>69a,69b</sup> P. Mastrandrea,<sup>71a,71b</sup> A. Mastroberardino,<sup>41b,41a</sup> T. Masubuchi,<sup>160</sup> T. Mathisen,<sup>168</sup>  
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F. Meloni,<sup>46</sup> A. Melzer,<sup>24</sup> E. D. Mendes Gouveia,<sup>137a</sup> A. M. Mendes Jacques Da Costa,<sup>20</sup> H. Y. Meng,<sup>163</sup> L. Meng,<sup>89</sup>  
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A. Milov,<sup>176</sup> D. A. Milstead,<sup>45a,45b</sup> T. Min,<sup>14c</sup> A. A. Minaenko,<sup>120</sup> I. A. Minashvili,<sup>156b</sup> L. Mince,<sup>57</sup> A. I. Mincer,<sup>123</sup>  
B. Mindur,<sup>83a</sup> M. Mineev,<sup>79</sup> Y. Minegishi,<sup>160</sup> Y. Mino,<sup>85</sup> L. M. Mir,<sup>13</sup> M. Miralles Lopez,<sup>170</sup> M. Mironova,<sup>132</sup> T. Mitani,<sup>175</sup>  
A. Mitra,<sup>174</sup> V. A. Mitsou,<sup>170</sup> O. Miu,<sup>163</sup> P. S. Miyagawa,<sup>92</sup> Y. Miyazaki,<sup>87</sup> A. Mizukami,<sup>81</sup> J. U. Mjörnmark,<sup>96</sup>  
T. Mkrtchyan,<sup>61a</sup> M. Mlynarikova,<sup>118</sup> T. Moa,<sup>45a,45b</sup> S. Mobius,<sup>53</sup> K. Mochizuki,<sup>108</sup> P. Moder,<sup>46</sup> P. Mogg,<sup>112</sup>  
A. F. Mohammed,<sup>14a</sup> S. Mohapatra,<sup>39</sup> G. Mokgatitswane,<sup>33g</sup> B. Mondal,<sup>148</sup> S. Mondal,<sup>139</sup> K. Mönig,<sup>46</sup> E. Monnier,<sup>100</sup>  
L. Monsonis Romero,<sup>170</sup> J. Montejo Berlingen,<sup>36</sup> M. Montella,<sup>125</sup> F. Monticelli,<sup>88</sup> N. Morange,<sup>64</sup>  
A. L. Moreira De Carvalho,<sup>137a</sup> M. Moreno Llácer,<sup>170</sup> C. Moreno Martinez,<sup>13</sup> P. Morettini,<sup>55b</sup> S. Morgenstern,<sup>174</sup> D. Mori,<sup>149</sup>  
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M. Mosidze,<sup>156b</sup> T. Moskalets,<sup>52</sup> P. Moskvitina,<sup>116</sup> J. Moss,<sup>31,ff</sup> E. J. W. Moyse,<sup>101</sup> S. Muanza,<sup>100</sup> J. Mueller,<sup>136</sup> R. Mueller,<sup>19</sup>  
D. Muenstermann,<sup>89</sup> G. A. Mullier,<sup>96</sup> J. J. Mullin,<sup>134</sup> D. P. Mungo,<sup>68a,68b</sup> J. L. Munoz Martinez,<sup>13</sup> F. J. Munoz Sanchez,<sup>99</sup>  
M. Murin,<sup>99</sup> W. J. Murray,<sup>174,141</sup> A. Murrone,<sup>68a,68b</sup> J. M. Muse,<sup>126</sup> M. Muškinja,<sup>17</sup> C. Mwewa,<sup>29</sup> A. G. Myagkov,<sup>120,k</sup>  
A. J. Myers,<sup>8</sup> A. A. Myers,<sup>136</sup> G. Myers,<sup>65</sup> M. Myska,<sup>139</sup> B. P. Nachman,<sup>17</sup> O. Nackenhorst,<sup>47</sup> A. Nag Nag,<sup>48</sup> K. Nagai,<sup>132</sup>  
K. Nagano,<sup>81</sup> J. L. Nagle,<sup>29</sup> E. Nagy,<sup>100</sup> A. M. Nairz,<sup>36</sup> Y. Nakahama,<sup>81</sup> K. Nakamura,<sup>81</sup> H. Nanjo,<sup>130</sup> F. Napolitano,<sup>61a</sup>  
R. Narayan,<sup>42</sup> E. A. Narayanan,<sup>115</sup> I. Naryshkin,<sup>135</sup> M. Naseri,<sup>34</sup> C. Nass,<sup>24</sup> G. Navarro,<sup>22a</sup> J. Navarro-Gonzalez,<sup>170</sup>  
R. Nayak,<sup>158</sup> P. Y. Nechaeva,<sup>109</sup> F. Nechansky,<sup>46</sup> T. J. Neep,<sup>20</sup> A. Negri,<sup>70a,70b</sup> M. Negrini,<sup>23b</sup> C. Nellist,<sup>116</sup> C. Nelson,<sup>102</sup>  
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P. R. Newman,<sup>20</sup> C. W. Ng,<sup>136</sup> Y. S. Ng,<sup>18</sup> Y. W. Y. Ng,<sup>167</sup> B. Ngair,<sup>35e</sup> H. D. N. Nguyen,<sup>108</sup> R. B. Nickerson,<sup>132</sup>  
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K. Nikolopoulos,<sup>20</sup> P. Nilsson,<sup>29</sup> H. R. Nindhito,<sup>54</sup> A. Nisati,<sup>72a</sup> N. Nishu,<sup>2</sup> R. Nisius,<sup>113</sup> S. J. Noacco Rosende,<sup>88</sup> T. Nobe,<sup>160</sup>  
D. L. Noel,<sup>32</sup> Y. Noguchi,<sup>85</sup> I. Nomidis,<sup>133</sup> M. A. Nomura,<sup>29</sup> M. B. Norfolk,<sup>146</sup> R. R. B. Norisam,<sup>94</sup> J. Novak,<sup>91</sup> T. Novak,<sup>46</sup>  
O. Novgorodova,<sup>48</sup> L. Novotny,<sup>139</sup> R. Novotny,<sup>115</sup> L. Nozka,<sup>128</sup> K. Ntekas,<sup>167</sup> E. Nurse,<sup>94</sup> F. G. Oakham,<sup>34,f</sup> J. Ocariz,<sup>133</sup>  
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S. A. Olivares Pino,<sup>144e</sup> D. Oliveira Damazio,<sup>29</sup> D. Oliveira Goncalves,<sup>80a</sup> J. L. Oliver,<sup>167</sup> M. J. R. Olsson,<sup>167</sup> A. Olszewski,<sup>84</sup>  
J. Olszowska,<sup>84</sup> Ö. O. Öncel,<sup>52</sup> D. C. O'Neil,<sup>149</sup> A. P. O'Neill,<sup>19</sup> A. Onofre,<sup>137a,137e</sup> P. U. E. Onyisi,<sup>11</sup>  
R. G. Oreamuno Madriz,<sup>118</sup> M. J. Oreglia,<sup>37</sup> G. E. Orellana,<sup>88</sup> D. Orestano,<sup>74a,74b</sup> N. Orlando,<sup>13</sup> R. S. Orr,<sup>163</sup> V. O'Shea,<sup>57</sup>  
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M. Palka,<sup>83b</sup> J. Pan,<sup>179</sup> D. K. Panchal,<sup>11</sup> C. E. Pandini,<sup>117</sup> J. G. Panduro Vazquez,<sup>93</sup> P. Pani,<sup>46</sup> G. Panizzo,<sup>66a,66c</sup> L. Paolozzi,<sup>54</sup>  
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 D. Pietreanu,<sup>27b</sup> A. D. Pilkington,<sup>99</sup> M. Pinamonti,<sup>66a,66c</sup> J. L. Pinfold,<sup>2</sup> C. Pitman Donaldson,<sup>94</sup> D. A. Pizzi,<sup>34</sup>  
 L. Pizzimento,<sup>73a,73b</sup> A. Pizzini,<sup>117</sup> M.-A. Pleier,<sup>29</sup> V. Plesanovs,<sup>52</sup> V. Pleskot,<sup>140</sup> E. Plotnikova,<sup>79</sup> G. Poddar,<sup>4</sup> R. Poettgen,<sup>96</sup>  
 R. Poggi,<sup>54</sup> L. Poggioli,<sup>133</sup> I. Pogrebnyak,<sup>105</sup> D. Pohl,<sup>24</sup> I. Pokharel,<sup>53</sup> S. Polacek,<sup>140</sup> G. Polesello,<sup>70a</sup> A. Poley,<sup>149,164a</sup>  
 R. Polifka,<sup>139</sup> A. Polini,<sup>23b</sup> C. S. Pollard,<sup>132</sup> Z. B. Pollock,<sup>125</sup> V. Polychronakos,<sup>29</sup> D. Ponomarenko,<sup>110</sup> L. Pontecorvo,<sup>36</sup>  
 S. Popa,<sup>27a</sup> G. A. Popeneciu,<sup>27d</sup> L. Portales,<sup>4</sup> D. M. Portillo Quintero,<sup>164a</sup> S. Pospisil,<sup>139</sup> P. Postolache,<sup>27c</sup> K. Potamianos,<sup>132</sup>  
 I. N. Potrap,<sup>79</sup> C. J. Potter,<sup>32</sup> H. Potti,<sup>1</sup> T. Poulsen,<sup>46</sup> J. Poveda,<sup>170</sup> G. Pownall,<sup>46</sup> M. E. Pozo Astigarraga,<sup>36</sup>  
 A. Prades Ibanez,<sup>170</sup> P. Pralavorio,<sup>100</sup> M. M. Prapa,<sup>44</sup> D. Price,<sup>99</sup> M. Primavera,<sup>67a</sup> M. A. Principe Martin,<sup>97</sup> M. L. Proffitt,<sup>145</sup>  
 N. Proklova,<sup>110</sup> K. Prokofiev,<sup>62c</sup> F. Prokoshin,<sup>79</sup> G. Proto,<sup>73a,73b</sup> S. Protopopescu,<sup>29</sup> J. Proudfoot,<sup>6</sup> M. Przybycien,<sup>83a</sup>  
 D. Pudzha,<sup>135</sup> P. Puzo,<sup>64</sup> D. Pyatiizbyantseva,<sup>110</sup> J. Qian,<sup>104</sup> Y. Qin,<sup>99</sup> T. Qiu,<sup>92</sup> A. Quadt,<sup>53</sup> M. Queitsch-Maitland,<sup>24</sup>  
 G. Rabanal Bolanos,<sup>59</sup> D. Rafanoharana,<sup>52</sup> F. Ragusa,<sup>68a,68b</sup> J. A. Raine,<sup>54</sup> S. Rajagopalan,<sup>29</sup> K. Ran,<sup>14a,14d</sup> V. Raskina,<sup>133</sup>  
 D. F. Rassloff,<sup>61a</sup> S. Rave,<sup>98</sup> B. Ravina,<sup>57</sup> I. Ravinovich,<sup>176</sup> M. Raymond,<sup>36</sup> A. L. Read,<sup>131</sup> N. P. Readioff,<sup>146</sup>  
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 M. Renda,<sup>27b</sup> M. B. Rendel,<sup>113</sup> A. G. Rennie,<sup>57</sup> S. Resconi,<sup>68a</sup> M. Ressegotti,<sup>55b,55a</sup> E. D. Resseguie,<sup>17</sup> S. Rettie,<sup>94</sup>  
 B. Reynolds,<sup>125</sup> E. Reynolds,<sup>17</sup> M. Rezaei Estabragh,<sup>178</sup> O. L. Rezanova,<sup>119b,119a</sup> P. Reznicek,<sup>140</sup> E. Ricci,<sup>75a,75b</sup> R. Richter,<sup>113</sup>  
 S. Richter,<sup>45a,45b</sup> E. Richter-Was,<sup>83b</sup> M. Ridel,<sup>133</sup> P. Rieck,<sup>123</sup> P. Riedler,<sup>36</sup> M. Rijssenbeek,<sup>152</sup> A. Rimoldi,<sup>70a,70b</sup>  
 M. Rimoldi,<sup>46</sup> L. Rinaldi,<sup>23b,23a</sup> T. T. Rinn,<sup>169</sup> M. P. Rinnagel,<sup>112</sup> G. Ripellino,<sup>151</sup> I. Riu,<sup>13</sup> P. Rivadeneira,<sup>46</sup>  
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 M. Robin,<sup>46</sup> D. Robinson,<sup>32</sup> C. M. Robles Gajardo,<sup>144f</sup> M. Robles Manzano,<sup>98</sup> A. Robson,<sup>57</sup> A. Rocchi,<sup>73a,73b</sup> C. Roda,<sup>71a,71b</sup>  
 S. Rodriguez Bosca,<sup>61a</sup> Y. Rodriguez Garcia,<sup>22a</sup> A. Rodriguez Rodriguez,<sup>52</sup> A. M. Rodríguez Vera,<sup>164b</sup> S. Roe,<sup>36</sup>  
 J. T. Roemer,<sup>167</sup> A. R. Roepe,<sup>126</sup> J. Roggel,<sup>178</sup> O. Røhne,<sup>131</sup> R. A. Rojas,<sup>172</sup> B. Roland,<sup>52</sup> C. P. A. Roland,<sup>65</sup> J. Roloff,<sup>29</sup>  
 A. Romaniouk,<sup>110</sup> M. Romano,<sup>23b</sup> A. C. Romero Hernandez,<sup>169</sup> N. Rompotis,<sup>90</sup> M. Ronzani,<sup>123</sup> L. Roos,<sup>133</sup> S. Rosati,<sup>72a</sup>  
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 D. Rousseau,<sup>64</sup> D. Rousso,<sup>32</sup> G. Rovelli,<sup>70a,70b</sup> A. Roy,<sup>169</sup> A. Rozanov,<sup>100</sup> Y. Rozen,<sup>157</sup> X. Ruan,<sup>33g</sup> A. J. Ruby,<sup>90</sup>  
 T. A. Ruggeri,<sup>1</sup> F. Rühr,<sup>52</sup> A. Ruiz-Martinez,<sup>170</sup> A. Rummler,<sup>36</sup> Z. Rurikova,<sup>52</sup> N. A. Rusakovich,<sup>79</sup> H. L. Russell,<sup>172</sup>  
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 T. Scanlon,<sup>94</sup> J. Schaarschmidt,<sup>145</sup> P. Schacht,<sup>113</sup> D. Schaefer,<sup>37</sup> U. Schäfer,<sup>98</sup> A. C. Schaffer,<sup>64</sup> D. Schaile,<sup>112</sup>  
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 K. E. Schleicher,<sup>52</sup> S. Schlenker,<sup>36</sup> K. Schmieden,<sup>98</sup> C. Schmitt,<sup>98</sup> S. Schmitt,<sup>46</sup> L. Schoeffel,<sup>142</sup> A. Schoening,<sup>61b</sup>  
 P. G. Scholer,<sup>52</sup> E. Schopf,<sup>132</sup> M. Schott,<sup>98</sup> J. Schovancova,<sup>36</sup> S. Schramm,<sup>54</sup> F. Schroeder,<sup>178</sup> H-C. Schultz-Coulon,<sup>61a</sup>  
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Solovyev,<sup>135</sup> P. Sommer,<sup>146</sup> H. Son,<sup>166</sup> A. Sonay,<sup>13</sup> W. Y. Song,<sup>164b</sup> A. Sopczak,<sup>139</sup> A. L. Sopio,<sup>94</sup> F. Sopkova,<sup>28b</sup> V. Sothilingam,<sup>61a</sup> S. Sottocornola,<sup>70a,70b</sup> R. Soualah,<sup>122c</sup> A. M. Soukharev,<sup>119b,119a</sup> Z. Soumami,<sup>35e</sup> D. South,<sup>46</sup> S. Spagnolo,<sup>67a,67b</sup> M. Spalla,<sup>113</sup> M. Spangenberg,<sup>174</sup> F. Spanò,<sup>93</sup> D. Sperlich,<sup>52</sup> G. Spigo,<sup>36</sup> M. Spina,<sup>153</sup> S. Spinali,<sup>89</sup> D. P. Spiteri,<sup>57</sup> M. Spousta,<sup>140</sup> E. J. Staats,<sup>34</sup> A. Stabile,<sup>68a,68b</sup> R. Stamen,<sup>61a</sup> M. Stamenkovic,<sup>117</sup> A. Stampekiš,<sup>20</sup> M. Standke,<sup>24</sup> E. Stanecka,<sup>84</sup> B. Stanislaus,<sup>17</sup> M. M. Stanitzki,<sup>46</sup> M. Stankaityte,<sup>132</sup> B. Stapf,<sup>46</sup> E. A. Starchenko,<sup>120</sup> G. H. Stark,<sup>143</sup> J. Stark,<sup>100</sup> D. M. Starko,<sup>164b</sup> P. Staroba,<sup>138</sup> P. Starovoitov,<sup>61a</sup> S. Stärz,<sup>102</sup> R. Staszewski,<sup>84</sup> G. Stavropoulos,<sup>44</sup> J. Steentoft,<sup>168</sup> P. Steinberg,<sup>29</sup> A. L. Steinhebel,<sup>129</sup> B. Stelzer,<sup>149,164a</sup> H. J. Stelzer,<sup>136</sup> O. Stelzer-Chilton,<sup>164a</sup> H. Stenzel,<sup>56</sup> T. J. Stevenson,<sup>153</sup> G. A. Stewart,<sup>36</sup> M. C. Stockton,<sup>36</sup> G. Stoicea,<sup>27b</sup> M. Stolarski,<sup>137a</sup> S. Stonjek,<sup>113</sup> A. Straessner,<sup>48</sup> J. Strandberg,<sup>151</sup> S. Strandberg,<sup>45a,45b</sup> M. Strauss,<sup>126</sup> T. Strebler,<sup>100</sup> P. Strizenec,<sup>28b</sup> R. Ströhmer,<sup>173</sup> D. M. Strom,<sup>129</sup> L. R. Strom,<sup>46</sup> R. Stroynowski,<sup>42</sup> A. Strubig,<sup>45a,45b</sup> S. A. Stucci,<sup>29</sup> B. Stugu,<sup>16</sup> J. Stupak,<sup>126</sup> N. A. Styles,<sup>46</sup> D. Su,<sup>150</sup> S. Su,<sup>60a</sup> W. Su,<sup>60d,145,60c</sup> X. Su,<sup>60a,64</sup> K. Sugizaki,<sup>160</sup> V. V. Sulin,<sup>109</sup> M. J. Sullivan,<sup>90</sup> D. M. S. Sultan,<sup>75a,75b</sup> L. Sultanaliev,<sup>109</sup> S. Sultansoy,<sup>3b</sup> T. Sumida,<sup>85</sup> S. Sun,<sup>104</sup> S. Sun,<sup>177</sup> O. Sunneborn Gudnadottir,<sup>168</sup> M. R. Sutton,<sup>153</sup> M. Svatos,<sup>138</sup> M. Swiatlowski,<sup>164a</sup> T. Swirski,<sup>173</sup> I. Sykora,<sup>28a</sup> M. Sykora,<sup>140</sup> T. Sykora,<sup>140</sup> D. Ta,<sup>98</sup> K. Tackmann,<sup>46,ii</sup> A. Taffard,<sup>167</sup> R. Tafirout,<sup>164a</sup> R. H. M. Taibah,<sup>133</sup> R. Takashima,<sup>86</sup> K. Takeda,<sup>82</sup> E. P. Takeva,<sup>50</sup> Y. Takubo,<sup>81</sup> M. Talby,<sup>100</sup> A. A. Talyshv,<sup>119b,119a</sup> K. C. Tam,<sup>62b</sup> N. M. Tamir,<sup>158</sup> A. Tanaka,<sup>160</sup> J. Tanaka,<sup>160</sup> R. Tanaka,<sup>64</sup> J. Tang,<sup>60c</sup> Z. Tao,<sup>171</sup> S. Tapia Araya,<sup>78</sup> S. Tapprogge,<sup>98</sup> A. Tarek Abouelfadl Mohamed,<sup>105</sup> S. Tarem,<sup>157</sup> K. Tariq,<sup>60b</sup> G. Tarna,<sup>27b</sup> G. F. Tartarelli,<sup>68a</sup> P. Tas,<sup>140</sup> M. Tasevsky,<sup>138</sup> E. Tassi,<sup>41b,41a</sup> G. Tateno,<sup>160</sup> Y. Tayalati,<sup>35e</sup> G. N. Taylor,<sup>103</sup> W. Taylor,<sup>164b</sup> H. Teagle,<sup>90</sup> A. S. Tee,<sup>177</sup> R. Teixeira De Lima,<sup>150</sup> P. Teixeira-Dias,<sup>93</sup> J. J. Teoh,<sup>117</sup> K. Terashi,<sup>160</sup> J. Terron,<sup>97</sup> S. Terzo,<sup>13</sup> M. Testa,<sup>51</sup> R. J. Teuscher,<sup>163,n</sup> N. Themistokleous,<sup>50</sup> T. Theveneaux-Pelzer,<sup>18</sup> O. Thielmann,<sup>178</sup> D. W. Thomas,<sup>93</sup> J. P. Thomas,<sup>20</sup> E. A. Thompson,<sup>46</sup> P. D. Thompson,<sup>20</sup> E. Thomson,<sup>134</sup> E. J. Thorpe,<sup>92</sup> Y. Tian,<sup>53</sup> V. Tikhomirov,<sup>109,ij</sup> Yu. A. Tikhonov,<sup>119b,119a</sup> S. Timoshenko,<sup>110</sup> E. X. L. Ting,<sup>1</sup> P. Tipton,<sup>179</sup> S. Tisserant,<sup>100</sup> S. H. Tlou,<sup>33g</sup> A. Tmourji,<sup>38</sup> K. Todome,<sup>23b,23a</sup> S. Todorova-Nova,<sup>140</sup> S. Todt,<sup>48</sup> M. Togawa,<sup>81</sup> J. Tojo,<sup>87</sup> S. Tokár,<sup>28a</sup> K. Tokushuku,<sup>81</sup> R. Tombs,<sup>32</sup> M. Tomoto,<sup>81,114</sup> L. Tompkins,<sup>150</sup> P. Tornambe,<sup>101</sup> E. Torrence,<sup>129</sup> H. Torres,<sup>48</sup> E. Torró Pastor,<sup>170</sup> M. Toscani,<sup>30</sup> C. Toscizi,<sup>37</sup> D. R. Tovey,<sup>146</sup> A. Traet,<sup>16</sup> I. S. Trandafir,<sup>27b</sup> C. J. Treado,<sup>123</sup> T. Trefzger,<sup>173</sup> A. Tricoli,<sup>29</sup> I. M. Trigger,<sup>164a</sup> S. Trincaz-Duvold,<sup>133</sup> D. A. Trischuk,<sup>171</sup> W. Trischuk,<sup>163</sup> B. Trocmé,<sup>58</sup> A. Trofymov,<sup>64</sup> C. Troncon,<sup>68a</sup> F. Trovato,<sup>153</sup> L. Truong,<sup>33c</sup> M. Trzebinski,<sup>84</sup> A. Trzupek,<sup>84</sup> F. Tsai,<sup>152</sup> M. Tsai,<sup>104</sup> A. Tsiamis,<sup>159</sup> P. V. Tsiareshka,<sup>106</sup> A. Tsirigotis,<sup>159,cc</sup> V. Tsiskaridze,<sup>152</sup> E. G. Tskhadadze,<sup>156a</sup> M. Tsooulou,<sup>159</sup> Y. Tsujikawa,<sup>85</sup> I. I. Tsukerman,<sup>121</sup> V. Tsulaia,<sup>17</sup> S. Tsuno,<sup>81</sup> O. Tsur,<sup>157</sup> D. Tsybychev,<sup>152</sup> Y. Tu,<sup>62b</sup> A. Tudorache,<sup>27b</sup> V. Tudorache,<sup>27b</sup> A. N. Tuna,<sup>36</sup> S. Turchikhin,<sup>79</sup> I. Turk Cakir,<sup>3a</sup> R. Turra,<sup>68a</sup> P. M. Tuts,<sup>39</sup> S. Tzamarias,<sup>159</sup> P. Tzani,<sup>10</sup> E. Tzovara,<sup>98</sup> K. Uchida,<sup>160</sup> F. Ukegawa,<sup>165</sup> P. A. Ulloa Poblete,<sup>144c</sup> G. Unal,<sup>36</sup> M. Unal,<sup>11</sup> A. Undrus,<sup>29</sup> G. Unel,<sup>167</sup> K. Uno,<sup>160</sup> J. Urban,<sup>28b</sup> P. Urquijo,<sup>103</sup> G. Usai,<sup>8</sup> R. Ushioda,<sup>161</sup> M. Usman,<sup>108</sup> Z. Uysal,<sup>21b</sup> V. Vacek,<sup>139</sup> B. Vachon,<sup>102</sup> K. O. H. Vadla,<sup>131</sup> T. Vafeiadis,<sup>36</sup> C. Valderanis,<sup>112</sup> E. Valdes Santurio,<sup>45a,45b</sup> M. Valente,<sup>164a</sup> S. Valentinetti,<sup>23b,23a</sup> A. Valero,<sup>170</sup> A. Vallier,<sup>100</sup> J. A. Valls Ferrer,<sup>170</sup> T. R. Van Daalen,<sup>145</sup> P. Van Gemmeren,<sup>6</sup> S. Van Stroud,<sup>94</sup> I. Van Vulpen,<sup>117</sup> M. Vanadia,<sup>73a,73b</sup> W. Vandelli,<sup>36</sup> M. Vandenbroucke,<sup>142</sup> E. R. Vandewall,<sup>127</sup> D. Vannicola,<sup>158</sup> L. Vannoli,<sup>55b,55a</sup> R. Vari,<sup>72a</sup> E. W. Varnes,<sup>7</sup> C. Varni,<sup>17</sup> T. Varol,<sup>155</sup> D. Varouchas,<sup>64</sup> K. E. Varvell,<sup>154</sup> M. E. Vasile,<sup>27b</sup> L. Vaslin,<sup>38</sup> G. A. Vasquez,<sup>172</sup> F. Vazeille,<sup>38</sup>

D. Vazquez Furelos,<sup>13</sup> T. Vazquez Schroeder,<sup>36</sup> J. Veatch,<sup>53</sup> V. Vecchio,<sup>99</sup> M. J. Veen,<sup>117</sup> I. Veliscek,<sup>132</sup> L. M. Veloce,<sup>163</sup>  
 F. Veloso,<sup>137a,137c</sup> S. Veneziano,<sup>72a</sup> A. Ventura,<sup>67a,67b</sup> A. Verbytskyi,<sup>113</sup> M. Verducci,<sup>71a,71b</sup> C. Vergis,<sup>24</sup>  
 M. Verissimo De Araujo,<sup>80b</sup> W. Verkerke,<sup>117</sup> J. C. Vermeulen,<sup>117</sup> C. Vernieri,<sup>150</sup> P. J. Verschuuren,<sup>93</sup> M. Vessella,<sup>101</sup>  
 M. L. Vesterbacka,<sup>123</sup> M. C. Vetterli,<sup>149,f</sup> A. Vgenopoulos,<sup>159</sup> N. Viaux Maira,<sup>144f</sup> T. Vickey,<sup>146</sup> O. E. Vickey Boeriu,<sup>146</sup>  
 G. H. A. Viehhauser,<sup>132</sup> L. Vigani,<sup>61b</sup> M. Villa,<sup>23b,23a</sup> M. Villaplana Perez,<sup>170</sup> E. M. Villhauer,<sup>50</sup> E. Vilucchi,<sup>51</sup>  
 M. G. Vincter,<sup>34</sup> G. S. Virdee,<sup>20</sup> A. Vishwakarma,<sup>50</sup> C. Vittori,<sup>23b,23a</sup> I. Vivarelli,<sup>153</sup> V. Vladimirov,<sup>174</sup> E. Voevodina,<sup>113</sup>  
 M. Vogel,<sup>178</sup> P. Vokac,<sup>139</sup> J. Von Ahnen,<sup>46</sup> E. Von Toerne,<sup>24</sup> B. Vormwald,<sup>36</sup> V. Vorobel,<sup>140</sup> K. Vorobev,<sup>110</sup> M. Vos,<sup>170</sup>  
 J. H. Vossebeld,<sup>90</sup> M. Vozak,<sup>117</sup> L. Vozdecky,<sup>92</sup> N. Vranjes,<sup>15</sup> M. Vranjes Milosavljevic,<sup>15</sup> V. Vrba,<sup>139,a</sup> M. Vreeswijk,<sup>117</sup>  
 N. K. Vu,<sup>100</sup> R. Vuillermet,<sup>36</sup> O. V. Vujanovic,<sup>98</sup> I. Vukotic,<sup>37</sup> S. Wada,<sup>165</sup> C. Wagner,<sup>101</sup> W. Wagner,<sup>178</sup> S. Wahdan,<sup>178</sup>  
 H. Wahlberg,<sup>88</sup> R. Wakasa,<sup>165</sup> M. Wakida,<sup>114</sup> V. M. Walbrecht,<sup>113</sup> J. Walder,<sup>141</sup> R. Walker,<sup>112</sup> W. Walkowiak,<sup>148</sup>  
 A. M. Wang,<sup>59</sup> A. Z. Wang,<sup>177</sup> C. Wang,<sup>60a</sup> C. Wang,<sup>60c</sup> H. Wang,<sup>17</sup> J. Wang,<sup>62a</sup> P. Wang,<sup>42</sup> R.-J. Wang,<sup>98</sup> R. Wang,<sup>59</sup>  
 R. Wang,<sup>6</sup> S. M. Wang,<sup>155</sup> S. Wang,<sup>60b</sup> T. Wang,<sup>60a</sup> W. T. Wang,<sup>77</sup> W. X. Wang,<sup>60a</sup> X. Wang,<sup>14c</sup> X. Wang,<sup>169</sup> X. Wang,<sup>60c</sup>  
 Y. Wang,<sup>60d</sup> Z. Wang,<sup>104</sup> Z. Wang,<sup>60d,49,60c</sup> Z. Wang,<sup>104</sup> A. Warburton,<sup>102</sup> R. J. Ward,<sup>20</sup> N. Warrack,<sup>57</sup> A. T. Watson,<sup>20</sup>  
 M. F. Watson,<sup>20</sup> G. Watts,<sup>145</sup> B. M. Waugh,<sup>94</sup> A. F. Webb,<sup>11</sup> C. Weber,<sup>29</sup> M. S. Weber,<sup>19</sup> S. A. Weber,<sup>34</sup> S. M. Weber,<sup>61a</sup>  
 C. Wei,<sup>60a</sup> Y. Wei,<sup>132</sup> A. R. Weidberg,<sup>132</sup> J. Weingarten,<sup>47</sup> M. Weirich,<sup>98</sup> C. Weiser,<sup>52</sup> T. Wenaus,<sup>29</sup> B. Wendland,<sup>47</sup>  
 T. Wengler,<sup>36</sup> N. S. Wenke,<sup>113</sup> N. Wermes,<sup>24</sup> M. Wessels,<sup>61a</sup> K. Whalen,<sup>129</sup> A. M. Wharton,<sup>89</sup> A. S. White,<sup>59</sup> A. White,<sup>8</sup>  
 M. J. White,<sup>1</sup> D. Whiteson,<sup>167</sup> L. Wickremasinghe,<sup>130</sup> W. Wiedenmann,<sup>177</sup> C. Wiel,<sup>48</sup> M. Wielers,<sup>141</sup> N. Wieseotte,<sup>98</sup>  
 C. Wiglesworth,<sup>40</sup> L. A. M. Wiik-Fuchs,<sup>52</sup> D. J. Wilbern,<sup>126</sup> H. G. Wilkens,<sup>36</sup> D. M. Williams,<sup>39</sup> H. H. Williams,<sup>134</sup>  
 S. Williams,<sup>32</sup> S. Willocq,<sup>101</sup> P. J. Windischhofer,<sup>132</sup> F. Winklmeier,<sup>129</sup> B. T. Winter,<sup>52</sup> M. Wittgen,<sup>150</sup> M. Wobisch,<sup>95</sup>  
 A. Wolf,<sup>98</sup> R. Wölker,<sup>132</sup> J. Wollrath,<sup>167</sup> M. W. Wolter,<sup>84</sup> H. Wolters,<sup>137a,137c</sup> V. W. S. Wong,<sup>171</sup> A. F. Wongel,<sup>46</sup> S. D. Worm,<sup>46</sup>  
 B. K. Wosiek,<sup>84</sup> K. W. Woźniak,<sup>84</sup> K. Wraight,<sup>57</sup> J. Wu,<sup>14a,14d</sup> S. L. Wu,<sup>177</sup> X. Wu,<sup>54</sup> Y. Wu,<sup>60a</sup> Z. Wu,<sup>142,60a</sup> J. Wuerzinger,<sup>132</sup>  
 T. R. Wyatt,<sup>99</sup> B. M. Wynne,<sup>50</sup> S. Xella,<sup>40</sup> L. Xia,<sup>14c</sup> M. Xia,<sup>14b</sup> J. Xiang,<sup>62c</sup> X. Xiao,<sup>104</sup> M. Xie,<sup>60a</sup> X. Xie,<sup>60a</sup> I. Xiotidis,<sup>153</sup>  
 D. Xu,<sup>14a</sup> H. Xu,<sup>60a</sup> H. Xu,<sup>60a</sup> L. Xu,<sup>60a</sup> R. Xu,<sup>134</sup> T. Xu,<sup>60a</sup> W. Xu,<sup>104</sup> Y. Xu,<sup>14b</sup> Z. Xu,<sup>60b</sup> Z. Xu,<sup>150</sup> B. Yabsley,<sup>154</sup>  
 S. Yacoob,<sup>33a</sup> N. Yamaguchi,<sup>87</sup> Y. Yamaguchi,<sup>161</sup> H. Yamauchi,<sup>165</sup> T. Yamazaki,<sup>17</sup> Y. Yamazaki,<sup>82</sup> J. Yan,<sup>60c</sup> S. Yan,<sup>132</sup>  
 Z. Yan,<sup>25</sup> H. J. Yang,<sup>60c,60d</sup> H. T. Yang,<sup>17</sup> S. Yang,<sup>60a</sup> T. Yang,<sup>62c</sup> X. Yang,<sup>60a</sup> X. Yang,<sup>14a</sup> Y. Yang,<sup>42</sup> Z. Yang,<sup>104,60a</sup>  
 W.-M. Yao,<sup>17</sup> Y. C. Yap,<sup>46</sup> H. Ye,<sup>14c</sup> J. Ye,<sup>42</sup> S. Ye,<sup>29</sup> X. Ye,<sup>60a</sup> I. Yeletsikh,<sup>79</sup> M. R. Yexley,<sup>89</sup> P. Yin,<sup>39</sup> K. Yorita,<sup>175</sup>  
 C. J. S. Young,<sup>52</sup> C. Young,<sup>150</sup> M. Yuan,<sup>104</sup> R. Yuan,<sup>60b,kk</sup> X. Yue,<sup>61a</sup> M. Zaazoua,<sup>35e</sup> B. Zabinski,<sup>84</sup> G. Zacharis,<sup>10</sup> E. Zaid,<sup>50</sup>  
 A. M. Zaitsev,<sup>120,k</sup> T. Zakareishvili,<sup>156b</sup> N. Zakharchuk,<sup>34</sup> S. Zambito,<sup>36</sup> D. Zanzi,<sup>52</sup> O. Zaplatilek,<sup>139</sup> S. V. Zeißner,<sup>47</sup>  
 C. Zeitnitz,<sup>178</sup> J. C. Zeng,<sup>169</sup> D. T. Zenger Jr.,<sup>26</sup> O. Zenin,<sup>120</sup> T. Ženiš,<sup>28a</sup> S. Zenz,<sup>92</sup> S. Zerradi,<sup>35a</sup> D. Zerwas,<sup>64</sup> B. Zhang,<sup>14c</sup>  
 D. F. Zhang,<sup>146</sup> G. Zhang,<sup>14b</sup> J. Zhang,<sup>6</sup> K. Zhang,<sup>14a</sup> L. Zhang,<sup>14c</sup> M. Zhang,<sup>169</sup> R. Zhang,<sup>177</sup> S. Zhang,<sup>104</sup> X. Zhang,<sup>60c</sup>  
 X. Zhang,<sup>60b</sup> Z. Zhang,<sup>64</sup> H. Zhao,<sup>145</sup> P. Zhao,<sup>49</sup> T. Zhao,<sup>60b</sup> Y. Zhao,<sup>143</sup> Z. Zhao,<sup>60a</sup> A. Zhemchugov,<sup>79</sup> Z. Zheng,<sup>150</sup>  
 D. Zhong,<sup>169</sup> B. Zhou,<sup>104</sup> C. Zhou,<sup>177</sup> H. Zhou,<sup>7</sup> N. Zhou,<sup>60c</sup> Y. Zhou,<sup>7</sup> C. G. Zhu,<sup>60b</sup> C. Zhu,<sup>14a,14d</sup> H. L. Zhu,<sup>60a</sup> H. Zhu,<sup>14a</sup>  
 J. Zhu,<sup>104</sup> Y. Zhu,<sup>60a</sup> X. Zhuang,<sup>14a</sup> K. Zhukov,<sup>109</sup> V. Zhulanov,<sup>119b,119a</sup> D. Zieminska,<sup>65</sup> N. I. Zimine,<sup>79</sup> S. Zimmermann,<sup>52,a</sup>  
 J. Zinsser,<sup>61b</sup> M. Ziolkowski,<sup>148</sup> L. Živković,<sup>15</sup> A. Zoccoli,<sup>23b,23a</sup> K. Zoch,<sup>54</sup> T. G. Zorbas,<sup>146</sup> O. Zormpa,<sup>44</sup>  
 W. Zou,<sup>39</sup> and L. Zwalinski<sup>36</sup>

(ATLAS Collaboration)

<sup>1</sup>Department of Physics, University of Adelaide, Adelaide, Australia<sup>2</sup>Department of Physics, University of Alberta, Edmonton AB, Canada<sup>3a</sup>Department of Physics, Ankara University, Ankara, Turkey<sup>3b</sup>Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey<sup>4</sup>LAPP, Univ. Savoie Mont Blanc, CNRS/IN2P3, Annecy, France<sup>5</sup>APC, Université Paris Cité, CNRS/IN2P3, Paris, France<sup>6</sup>High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America<sup>7</sup>Department of Physics, University of Arizona, Tucson, Arizona, USA<sup>8</sup>Department of Physics, University of Texas at Arlington, Arlington, Texas, USA<sup>9</sup>Physics Department, National and Kapodistrian University of Athens, Athens, Greece<sup>10</sup>Physics Department, National Technical University of Athens, Zografou, Greece<sup>11</sup>Department of Physics, University of Texas at Austin, Austin, Texas, USA<sup>12</sup>Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan



- <sup>13</sup>*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
- <sup>14a</sup>*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
- <sup>14b</sup>*Physics Department, Tsinghua University, Beijing, China*
- <sup>14c</sup>*Department of Physics, Nanjing University, Nanjing, China*
- <sup>14d</sup>*University of Chinese Academy of Science (UCAS), Beijing, China*
- <sup>15</sup>*Institute of Physics, University of Belgrade, Belgrade, Serbia*
- <sup>16</sup>*Department for Physics and Technology, University of Bergen, Bergen, Norway*
- <sup>17</sup>*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
- <sup>18</sup>*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
- <sup>19</sup>*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
- <sup>20</sup>*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
- <sup>21a</sup>*Department of Physics, Bogazici University, Istanbul, Turkey*
- <sup>21b</sup>*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
- <sup>21c</sup>*Department of Physics, Istanbul University, Istanbul, Turkey*
- <sup>21d</sup>*Istinye University, Sariyer, Istanbul, Turkey*
- <sup>22a</sup>*Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá, Colombia*
- <sup>22b</sup>*Departamento de Física, Universidad Nacional de Colombia, Bogotá, Colombia*
- <sup>23a</sup>*Dipartimento di Fisica e Astronomia A. Righi, Università di Bologna, Bologna, Italy*
- <sup>23b</sup>*INFN Sezione di Bologna, Italy*
- <sup>24</sup>*Physikalisches Institut, Universität Bonn, Bonn, Germany*
- <sup>25</sup>*Department of Physics, Boston University, Boston, Massachusetts, USA*
- <sup>26</sup>*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
- <sup>27a</sup>*Transilvania University of Brasov, Brasov, Romania*
- <sup>27b</sup>*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
- <sup>27c</sup>*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
- <sup>27d</sup>*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
- <sup>27e</sup>*University Politehnica Bucharest, Bucharest, Romania*
- <sup>27f</sup>*West University in Timisoara, Timisoara, Romania*
- <sup>28a</sup>*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
- <sup>28b</sup>*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
- <sup>29</sup>*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
- <sup>30</sup>*Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, y CONICET, Instituto de Física de Buenos Aires (IFIBA), Buenos Aires, Argentina*
- <sup>31</sup>*California State University, California, USA*
- <sup>32</sup>*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
- <sup>33a</sup>*Department of Physics, University of Cape Town, Cape Town, South Africa*
- <sup>33b</sup>*iThemba Labs, Western Cape, South Africa*
- <sup>33c</sup>*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
- <sup>33d</sup>*National Institute of Physics, University of the Philippines Diliman (Philippines), Philippines*
- <sup>33e</sup>*University of South Africa, Department of Physics, Pretoria, South Africa*
- <sup>33f</sup>*University of Zululand, KwaDlangezwa, South Africa*
- <sup>33g</sup>*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
- <sup>34</sup>*Department of Physics, Carleton University, Ottawa ON, Canada*
- <sup>35a</sup>*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco*
- <sup>35b</sup>*Faculté des Sciences, Université Ibn-Tofail, Kénitra, Morocco*
- <sup>35c</sup>*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
- <sup>35d</sup>*LPMR, Faculté des Sciences, Université Mohamed Premier, Oujda, Morocco*
- <sup>35e</sup>*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
- <sup>35f</sup>*Mohammed VI Polytechnic University, Ben Guerir, Morocco*
- <sup>36</sup>*CERN, Geneva, Switzerland*
- <sup>37</sup>*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
- <sup>38</sup>*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
- <sup>39</sup>*Nevis Laboratory, Columbia University, Irvington, New York, USA*
- <sup>40</sup>*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
- <sup>41a</sup>*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
- <sup>41b</sup>*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
- <sup>42</sup>*Physics Department, Southern Methodist University, Dallas, Texas, USA*
- <sup>43</sup>*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*

- <sup>44</sup>*National Centre for Scientific Research “Demokritos”, Agia Paraskevi, Greece*  
<sup>45a</sup>*Department of Physics, Stockholm University, Sweden*  
<sup>45b</sup>*Oskar Klein Centre, Stockholm, Sweden*
- <sup>46</sup>*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*  
<sup>47</sup>*Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany*  
<sup>48</sup>*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*  
<sup>49</sup>*Department of Physics, Duke University, Durham, North Carolina, USA*
- <sup>50</sup>*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*  
<sup>51</sup>*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
- <sup>52</sup>*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*  
<sup>53</sup>*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
- <sup>54</sup>*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*  
<sup>55a</sup>*Dipartimento di Fisica, Università di Genova, Genova, Italy*  
<sup>55b</sup>*INFN Sezione di Genova, Italy*
- <sup>56</sup>*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
- <sup>57</sup>*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*  
<sup>58</sup>*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
- <sup>59</sup>*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*  
<sup>60a</sup>*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*  
<sup>60b</sup>*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
- <sup>60c</sup>*School of Physics and Astronomy, Shanghai Jiao Tong University, Key Laboratory for Particle Astrophysics and Cosmology (MOE), SKLPPC, Shanghai, China*  
<sup>60d</sup>*Tsung-Dao Lee Institute, Shanghai, China*
- <sup>61a</sup>*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*  
<sup>61b</sup>*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
- <sup>62a</sup>*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*  
<sup>62b</sup>*Department of Physics, University of Hong Kong, Hong Kong, China*  
<sup>62c</sup>*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
- <sup>63</sup>*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*  
<sup>64</sup>*IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay, France*
- <sup>65</sup>*Department of Physics, Indiana University, Bloomington, Indiana, USA*  
<sup>66a</sup>*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*  
<sup>66b</sup>*ICTP, Trieste, Italy*
- <sup>66c</sup>*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*  
<sup>67a</sup>*INFN Sezione di Lecce, Italy*
- <sup>67b</sup>*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*  
<sup>68a</sup>*INFN Sezione di Milano, Italy*  
<sup>68b</sup>*Dipartimento di Fisica, Università di Milano, Milano, Italy*  
<sup>69a</sup>*INFN Sezione di Napoli, Italy*
- <sup>69b</sup>*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*  
<sup>70a</sup>*INFN Sezione di Pavia, Italy*  
<sup>70b</sup>*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*  
<sup>71a</sup>*INFN Sezione di Pisa, Italy*
- <sup>71b</sup>*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*  
<sup>72a</sup>*INFN Sezione di Roma, Italy*  
<sup>72b</sup>*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*  
<sup>73a</sup>*INFN Sezione di Roma Tor Vergata, Italy*
- <sup>73b</sup>*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*  
<sup>74a</sup>*INFN Sezione di Roma Tre, Italy*
- <sup>74b</sup>*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*  
<sup>75a</sup>*INFN-TIFPA, Italy*  
<sup>75b</sup>*Università degli Studi di Trento, Trento, Italy*
- <sup>76</sup>*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*  
<sup>77</sup>*University of Iowa, Iowa City, Iowa, USA*
- <sup>78</sup>*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*  
<sup>79</sup>*Joint Institute for Nuclear Research, Dubna, Russia*
- <sup>80a</sup>*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*

- <sup>80b</sup>*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
- <sup>80c</sup>*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
- <sup>80d</sup>*Rio de Janeiro State University, Rio de Janeiro, Brazil*
- <sup>81</sup>*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
- <sup>82</sup>*Graduate School of Science, Kobe University, Kobe, Japan*
- <sup>83a</sup>*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
- <sup>83b</sup>*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
- <sup>84</sup>*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
- <sup>85</sup>*Faculty of Science, Kyoto University, Kyoto, Japan*
- <sup>86</sup>*Kyoto University of Education, Kyoto, Japan*
- <sup>87</sup>*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
- <sup>88</sup>*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
- <sup>89</sup>*Physics Department, Lancaster University, Lancaster, United Kingdom*
- <sup>90</sup>*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
- <sup>91</sup>*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
- <sup>92</sup>*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
- <sup>93</sup>*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
- <sup>94</sup>*Department of Physics and Astronomy, University College London, London, United Kingdom*
- <sup>95</sup>*Louisiana Tech University, Ruston, Los Angeles, USA*
- <sup>96</sup>*Fysiska institutionen, Lunds universitet, Lund, Sweden*
- <sup>97</sup>*Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
- <sup>98</sup>*Institut für Physik, Universität Mainz, Mainz, Germany*
- <sup>99</sup>*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
- <sup>100</sup>*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
- <sup>101</sup>*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
- <sup>102</sup>*Department of Physics, McGill University, Montreal QC, Canada*
- <sup>103</sup>*School of Physics, University of Melbourne, Victoria, Australia*
- <sup>104</sup>*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
- <sup>105</sup>*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
- <sup>106</sup>*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
- <sup>107</sup>*Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
- <sup>108</sup>*Group of Particle Physics, University of Montreal, Montreal QC, Canada*
- <sup>109</sup>*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
- <sup>110</sup>*National Research Nuclear University MEPhI, Moscow, Russia*
- <sup>111</sup>*D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
- <sup>112</sup>*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
- <sup>113</sup>*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
- <sup>114</sup>*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
- <sup>115</sup>*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
- <sup>116</sup>*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University/Nikhef, Nijmegen, Netherlands*
- <sup>117</sup>*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
- <sup>118</sup>*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
- <sup>119a</sup>*Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia*
- <sup>119b</sup>*Novosibirsk State University Novosibirsk, Russia*
- <sup>120</sup>*Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia*
- <sup>121</sup>*Institute for Theoretical and Experimental Physics named by A.I. Alihanov of National Research Centre “Kurchatov Institute”, Moscow, Russia*
- <sup>122a</sup>*New York University Abu Dhabi, Abu Dhabi, United Arab Emirates*
- <sup>122b</sup>*United Arab Emirates University, Al Ain, United Arab Emirates*
- <sup>122c</sup>*University of Sharjah, Sharjah, United Arab Emirates*
- <sup>123</sup>*Department of Physics, New York University, New York, New York, USA*
- <sup>124</sup>*Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo, Japan*
- <sup>125</sup>*Ohio State University, Columbus, Ohio, USA*
- <sup>126</sup>*Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA*
- <sup>127</sup>*Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA*
- <sup>128</sup>*Palacký University, Joint Laboratory of Optics, Olomouc, Czech Republic*
- <sup>129</sup>*Institute for Fundamental Science, University of Oregon, Eugene, Oregon, USA*
- <sup>130</sup>*Graduate School of Science, Osaka University, Osaka, Japan*
- <sup>131</sup>*Department of Physics, University of Oslo, Oslo, Norway*

- <sup>132</sup>*Department of Physics, Oxford University, Oxford, United Kingdom*
- <sup>133</sup>*LPNHE, Sorbonne Université, Université Paris Cité, CNRS/IN2P3, Paris, France*
- <sup>134</sup>*Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA*
- <sup>135</sup>*Konstantinov Nuclear Physics Institute of National Research Centre “Kurchatov Institute”, PNPI, St. Petersburg, Russia*
- <sup>136</sup>*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA*
- <sup>137a</sup>*Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Lisboa, Portugal*
- <sup>137b</sup>*Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal*
- <sup>137c</sup>*Departamento de Física, Universidade de Coimbra, Coimbra, Portugal*
- <sup>137d</sup>*Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal*
- <sup>137e</sup>*Departamento de Física, Universidade do Minho, Braga, Portugal*
- <sup>137f</sup>*Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain), Spain*
- <sup>137g</sup>*Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*
- <sup>138</sup>*Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic*
- <sup>139</sup>*Czech Technical University in Prague, Prague, Czech Republic*
- <sup>140</sup>*Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic*
- <sup>141</sup>*Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom*
- <sup>142</sup>*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
- <sup>143</sup>*Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA*
- <sup>144a</sup>*Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile*
- <sup>144b</sup>*Millennium Institute for Subatomic physics at high energy frontier (SAPHIR), Santiago, Chile*
- <sup>144c</sup>*Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, y Departamento de Física, Universidad de La Serena, Chile*
- <sup>144d</sup>*Universidad Andres Bello, Department of Physics, Santiago, Chile*
- <sup>144e</sup>*Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile*
- <sup>144f</sup>*Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile*
- <sup>145</sup>*Department of Physics, University of Washington, Seattle, Washington, USA*
- <sup>146</sup>*Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom*
- <sup>147</sup>*Department of Physics, Shinshu University, Nagano, Japan*
- <sup>148</sup>*Department Physik, Universität Siegen, Siegen, Germany*
- <sup>149</sup>*Department of Physics, Simon Fraser University, Burnaby BC, Canada*
- <sup>150</sup>*SLAC National Accelerator Laboratory, Stanford, California, USA*
- <sup>151</sup>*Department of Physics, Royal Institute of Technology, Stockholm, Sweden*
- <sup>152</sup>*Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA*
- <sup>153</sup>*Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom*
- <sup>154</sup>*School of Physics, University of Sydney, Sydney, Australia*
- <sup>155</sup>*Institute of Physics, Academia Sinica, Taipei, Taiwan*
- <sup>156a</sup>*E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia*
- <sup>156b</sup>*High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia*
- <sup>157</sup>*Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel*
- <sup>158</sup>*Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel*
- <sup>159</sup>*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
- <sup>160</sup>*International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan*
- <sup>161</sup>*Department of Physics, Tokyo Institute of Technology, Tokyo, Japan*
- <sup>162</sup>*Tomsk State University, Tomsk, Russia*
- <sup>163</sup>*Department of Physics, University of Toronto, Toronto ON, Canada*
- <sup>164a</sup>*TRIUMF, Vancouver BC, Canada*
- <sup>164b</sup>*Department of Physics and Astronomy, York University, Toronto ON, Canada*
- <sup>165</sup>*Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan*
- <sup>166</sup>*Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA*
- <sup>167</sup>*Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA*
- <sup>168</sup>*Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden*
- <sup>169</sup>*Department of Physics, University of Illinois, Urbana, Illinois, USA*
- <sup>170</sup>*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*
- <sup>171</sup>*Department of Physics, University of British Columbia, Vancouver BC, Canada*
- <sup>172</sup>*Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada*
- <sup>173</sup>*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
- <sup>174</sup>*Department of Physics, University of Warwick, Coventry, United Kingdom*
- <sup>175</sup>*Waseda University, Tokyo, Japan*
- <sup>176</sup>*Department of Particle Physics and Astrophysics, Weizmann Institute of Science, Rehovot, Israel*

<sup>177</sup>*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*

<sup>178</sup>*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*

<sup>179</sup>*Department of Physics, Yale University, New Haven, Connecticut, USA*

<sup>a</sup>Deceased.

<sup>b</sup>Also at Department of Physics, King's College London, London, United Kingdom.

<sup>c</sup>Also at Istanbul University, Dept. of Physics, Istanbul, Turkey.

<sup>d</sup>Also at Instituto de Fisica Teorica, IFT-UAM/CSIC, Madrid, Spain.

<sup>e</sup>Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.

<sup>f</sup>Also at TRIUMF, Vancouver BC, Canada.

<sup>g</sup>Also at Physics Department, An-Najah National University, Nablus, Palestinian Authority.

<sup>h</sup>Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.

<sup>i</sup>Also at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.

<sup>j</sup>Also at Departament de Fisica de la Universitat Autònoma de Barcelona, Barcelona, Spain.

<sup>k</sup>Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.

<sup>l</sup>Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva, Israel.

<sup>m</sup>Also at Università di Napoli Parthenope, Napoli, Italy.

<sup>n</sup>Also at Institute of Particle Physics (IPP), Canada.

<sup>o</sup>Also at Bruno Kessler Foundation, Trento, Italy.

<sup>p</sup>Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.

<sup>q</sup>Also at Borough of Manhattan Community College, City University of New York, New York, New York, USA.

<sup>r</sup>Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.

<sup>s</sup>Also at Centro Studi e Ricerche Enrico Fermi, Italy.

<sup>t</sup>Also at Department of Physics, California State University, East Bay, USA.

<sup>u</sup>Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.

<sup>v</sup>Also at Graduate School of Science, Osaka University, Osaka, Japan.

<sup>w</sup>Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.

<sup>x</sup>Also at University of Chinese Academy of Sciences (UCAS), Beijing, China.

<sup>y</sup>Also at Joint Institute for Nuclear Research, Dubna, Russia.

<sup>z</sup>Also at Yeditepe University, Physics Department, Istanbul, Turkey.

<sup>aa</sup>Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.

<sup>bb</sup>Also at CERN, Geneva, Switzerland.

<sup>cc</sup>Also at Hellenic Open University, Patras, Greece.

<sup>dd</sup>Also at Center for High Energy Physics, Peking University, China.

<sup>ee</sup>Also at The City College of New York, New York, New York, USA.

<sup>ff</sup>Also at Department of Physics, California State University, Sacramento, USA.

<sup>gg</sup>Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.

<sup>hh</sup>Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow, Russia.

<sup>ii</sup>Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.

<sup>jj</sup>Also at National Research Nuclear University MEPhI, Moscow, Russia.

<sup>kk</sup>Also at Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA.